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Final Report

for

Fine Attitude Control System
Phase I

July, 1965

SGC 742R-8

Contract No. NAS5-9056

Volume II of II

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Prepared by

Space-General Corporation
9200 East Flair Drive
El Monte, California

for

Goddard Space Flight Center
Greenbelt, Maryland

SPACE GENERAL TIRE GENERAL

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Appendix I

FUNCTIONAL DESCRIPTIONS AND SCHEMATICS

This appendix provides detailed descriptions of operation for each of the breadboard FACS subassemblies, modules, and associated Ground Support Equipment.

CONTENTS

A. STATIC INVERTER

REQUIREMENTS

The two-phase, sine-wave static inverter supplies the necessary AC power to the attitude control system. The inverter is designed to meet the following electrical requirements:

Line Voltage	24 VDC to 34 VDC
Output Voltage	
Zero Phase	13V and 26V rms
90° Phase	13V and 26V rms
Full Load	125 VA per phase
Total Harmonic Distortion	5%
Frequency	400 cps ± 0.25%
Phase	$90^{\circ} \pm 5^{\circ}$
Regulation	± 2%
Temperature (Ambient)	0°C to 60°C
(with adequate heat sink)	
Short Circuit Protected	

GENERAL

A schematic diagram of the static inverter is shown in Figure I-1. The output of a 400-cycle sine-wave oscillator is amplified in a Class A amplifier which is transformer-coupled to a Class B output amplifier. The zero phase signal is the transformed output from this amplifier.

An RC lag network is used to phase shift the zero phase signal 90°. The output signal from the lag network is amplified by a Class A amplifier and then a Class B amplifier as in the zero phase channel.

A current transformer is used in series with each output to indicate when a short circuit condition exists and to supply current feedback signals for voltage regulation with variations in load. In addition, a voltage feedback signal is obtained from the zero phase channel to drive a voltage regulating circuit which controls the amplitude of the sine-wave oscillator. Thus, the zero phase output signal is quite stable, and, since this signal is the input signal to the other channel, the 90° phase output signal is stable also.

It is desirable to run much of the internal circuitry from a regulated source. Therefore, a 24-volt regulator is included as part of the static inverter. The two-phase output signals are rectified and filtered to supply the input voltage for the regulator when the line voltage falls below about 26 VDC. Thus the inverter is capable of operation at quite low line voltages, i.e., 20 to 22 VDC.

A one-shot multivibrator is used in conjunction with the current transformers to disable the inverter when an output short circuit exists. The system is disabled for approximately 0.75 second each time the one-shot is triggered. In the event of a continuous short circuit, the system is cycled on and off continuously with an average output current well below the design value. The inverter returns to normal operation within approximately 1 second after removal of the short circuit condition.

DETAIL

A detailed description of the static inverter starts with the 24-volt regulator. A Darlington connection is used between transistors Q1 and Q2 where transistor Q1 is the series regulating transistor. The Darlington connection is used to increase the effective current gain, β, of the series transistor Q1. Resistor R1 is used to supply the required base current to transistor Q2. Zener diode CR5 establishes the voltage reference for the regulator. The required zener current is supplied from the regulated output voltage through resistor R2. Zener diode CR3 is used to increase the effective voltage gain of the regulator, thereby improving the regulation characteristics. Resistors R3, R4, and R57 comprise a voltage divider to supply the control transistor Q3 with a feedback signal. The emitter of transistor Q3 is at an essentially constant voltage. If the output voltage rises, the base current of Q3 increases; therefore the collector current of Q3 increases, causing the voltage at the base of Q2 to decrease. Thus, the output voltage decreases, and regulation is accomplished. Potentiometer R4 is used to set the output voltage to the design level. Capacitor C1 is used for filtering the noise purposes.

The tank of the sine-wave oscillator is comprised of inductor L1 and capacitors C2, C3, C4, and C5. Capacitor C5 is selectable to achieve a resonant frequency of 400 cps. The choice of the type of capacitors and the type of inductor was based upon the stability required of these components in the particular application. Transistor Q4 is the active element in the oscillator. Resistors R5, R6, R7, and R8 are used to set a stable operating point for transistor Q4. The oscillator feedback signal is inserted at the junction of resistors R7 and R8, and the output signal is taken from the same point.

The zero phase Class A amplifier is composed of transistors Q8, Q9, and Q10. Transistor Q8 is connected in a conventional manner for voltage amplification. Positive feedback from the output current transformer T3 is coupled through resistor R22 to the emitter of transistor Q8. The Darlington connection is used again with transistors Q9 and Q10 in an emitter follower configuration to obtain a low output impedance. Transformer T1 is used for voltage gain and for coupling from the Class A stage to the Class B stage.

The output amplifier is of the Class B type to improve the inverter efficiency and thereby indirectly reduce the power dissipation in the output transistors. The theoretical maximum efficiency for a Class B stage is approximately 78.5% whereas that for a Class A stage is 50%. Transistors Q13 and Q16 are paralleled with identical transistors to provide the required output power. A triple Darlington connection is used on each half of the Class B stage to provide the required current gain, and the emitter follower connection is used to yield a very low output impedance. Resistors R25, R26, R27, and R28 insure that thermal runaway does not occur. Diodes CR16 and CR17 and resistor R24 establish sufficient bias to reduce crossover distortion. Diodes are used so that the bias voltage is predictably variable with temperature changes. Thus, the DC standby current through the output transistors (Q13 and Q16) is additionally stabilized.

A phase shift circuit which consists of resistors R60, R40, R62, and capacitors C13 and C14 is used to phase shift the reference phase 90°. Temperature stable components are chosen to insure a stable phase shift. Potentiometer R40 is used to set the total phase shift to 90°. Potentiometer R39 is used to set the output voltage of the 90° phase to 26 volts rms. To attain a constant phase shift through the phase shift network, a fixed high impedance is used to couple the output signal from the network to the next voltage amplifier. An emitter follower stage composed of transistor Q19 and resistors R41, R42, and R44 is used to provide the required buffering.

The Class A amplifier and the Class B amplifier are the same as those in the zero phase channel.

Short circuit protection is accomplished with a one-shot multivibrator which, when activated, disables the Class A amplifiers in both channels. The active components in the one-shot are transistors Q17 and Q18. The time interval in the transient state of the one-shot is determined by resistor R35 and capacitor C12. Diode CR21 and capacitor C19 are used to prevent false triggering from possible transients on the 24-VDC line.

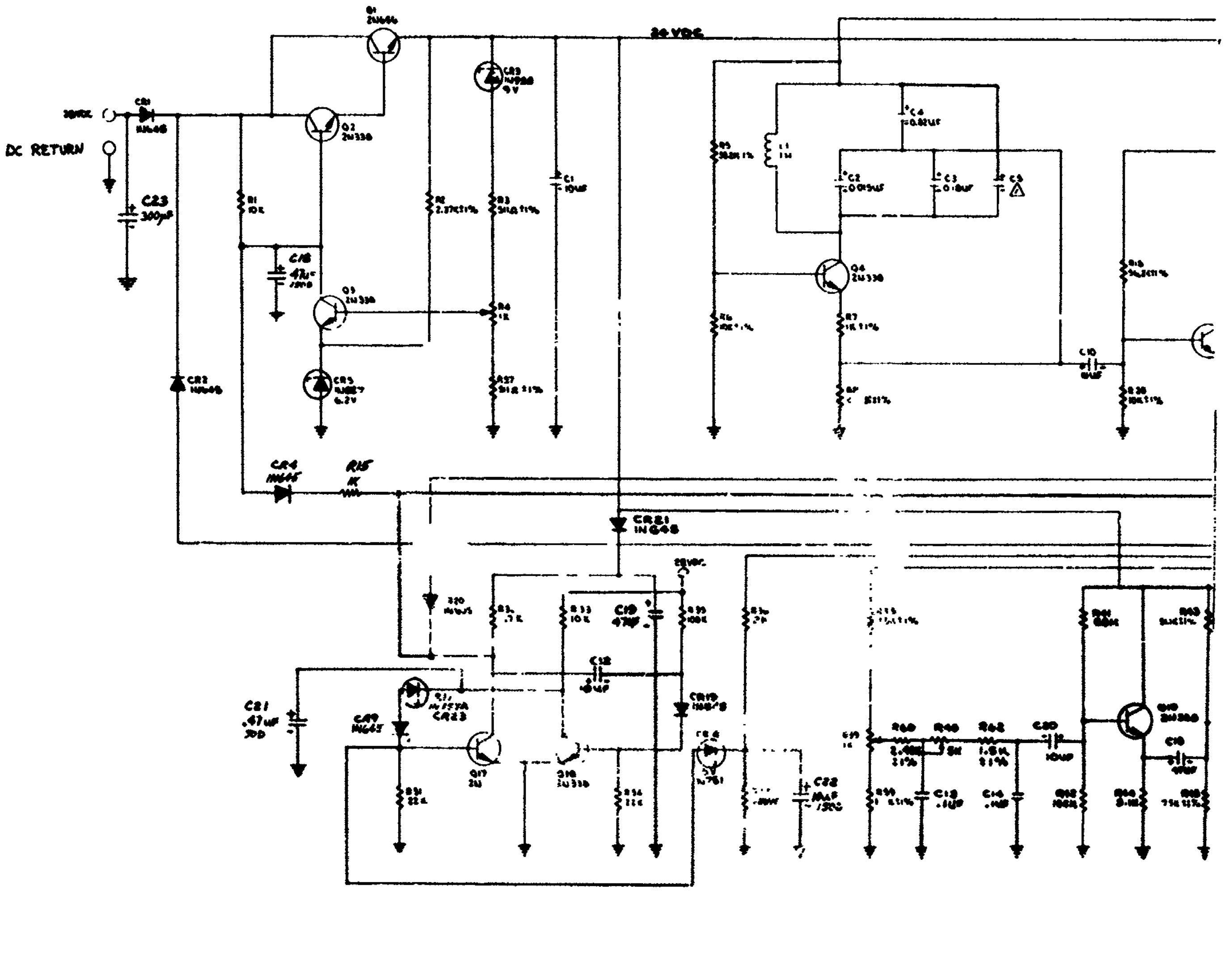

Figure I-1. Schematic, Static I

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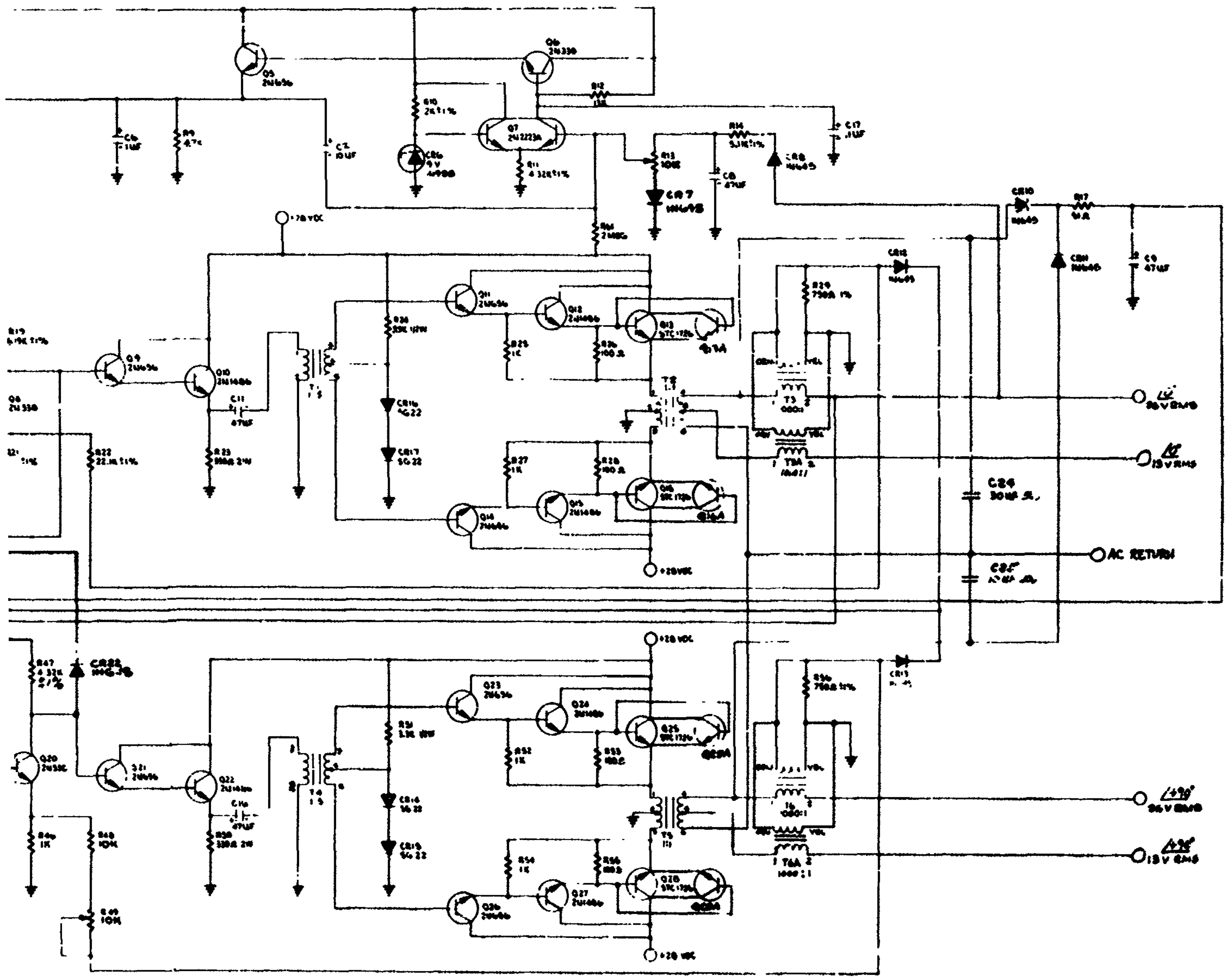

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verter Subassembly (Sketch 742-B-10)

B. DC POWER SUPPLY

ELECTRICAL DESIGN PARAMETERS

The +15-VDC supply provides a nominal output current of 500 ma with a design capability of 750 ma. The -15-VDC supply provides a nominal output current of 400 ma with a 750-ma design capability.

The nominal 15-volt output level of both supplies is adjustable over a limited range from approximately 13.8 to 16.1 volts. This is accomplished by potentiometer R9 (or R9A) in the attenuator network at the base on the signal side of the first differential amplifier.

The output voltage regulation of both supplies is 0.1% (maximum for an output load variation of one-half to full load). Output regulation of 0.1% is obtained over a temperature operating range of 32°F to 140°F. Output voltage ripple content is not greater than 5 mv rms.

Short circuit protection is provided for both the +15-VDC and -15-VDC supplies.

GENERAL

The DC power supply includes the +15-VDC and -15-VDC regulated supplies (see Figure I-2). The input power for the +15-VDC supply is provided by the system +28-VDC supply (batteries). The -15-VDC supply input power is supplied by the static inverter unit. Transformer T1 has a single primary and a center-tapped secondary winding. The primary winding is connected to the +90° phase of the 26-volt rms two-phase output from the static inverter unit. The center-tapped secondary is connected to a full-wave rectifier circuit. The output of the full-wave rectifier circuit is filtered by a single section choke input filter. The components of this filter are shown as choke L1 and capacitor C1. The voltage output from the filter section is then applied to the input of a series regulator circuit.

The series regulator circuits in these supplies require high-gain feedback circuits in order to obtain well regulated +15-VDC and -15-VDC output voltages. These supplies are the sources of DC input power to many critical control circuits in the FACS system.

SERIES REGULATOR CIRCUITS

The output voltage from the choke input filter in the -15-VDC supply is applied to a series regulator circuit. In the +15-VDC supply, the system battery voltage is applied directly to a series regulator. The series regulator circuits for the +15-VDC and -15-VDC supplies are mechanically and electronically identical. The components of each regulator circuit are mounted on a separate circuit board assembly.

In the -15-VDC regulator, the average voltage output from the choke input filter is approximately 24 volts. Transistor Q2 (or Q2A) drives the base of Q1 (or Q1A) in a Darlington circuit configuration for increased current gain. The remainder of the regulator feedback loop consists of a two-stage differential amplifier.

A portion of the regulated output voltage is differentially compared with a reference voltage source in the first differential amplifier stage (both halves of Q4 or Q4A). The reference source is a 6.2-volt zener reference diode CR3 (or CR3A) connected to the base of the reference half of the first stage. This diode is a type 1N827 which has an extremely low voltage temperature coefficient of 0.001% per degree centigrade. To obtain this low temperature coefficient requires a relatively constant reference current through the diode of approximately 7 milliamperes.

The differential output from the first amplifier stage Q4 (or Q4A) is direct-coupled to the base of the second differential amplifier stage Q3 (or Q3A). A single-ended output from the second differential amplifier stage is direct-coupled to the base of the first transistor Q2 (or Q2A) of the Darlington output connection. The Darlington connection provides increased current gain between the second differential amplifier and the series regulator transistor Q1 (or Q1A).

Both transistors of each differential amplifier stage are contained in a single electronic assembly which is a purchased item supplied from the manufacturer (Fairchild Semiconductor Corp.) as a type 2N2223A. This permits both transistor junctions to be subjected to almost identical temperature variations.

Then, critical transistor parameter variations due to temperature changes can be closely controlled so that the electrical performance of the differential amplifier stages can be closely predictable over a wide range of temperature. The advantages obtained in using a common electronic assembly such as the 2N2223A for differential amplifier applications are indicated by the following specification:

a. Differential base-to-emitter voltage between both transistor sections.

   $(V_{BE1} - V_{BE2}) = 0.005$ V (max)

b. Differential base-to-emitter voltage change with temperature between both transistor sections.

   $(\Delta V_{BE1} - \Delta V_{BE2}) = 25\ \mu v/^{\circ}C$ (max) from $-55^{\circ}C$ to $+125^{\circ}C$

c. DC current gain ratio between the transistor sections.

   $$0.90 \leq \frac{h_{FE1}}{h_{FE2}} \leq 1.11$$

d. Relatively high DC current gain for each section at low collector current levels.

   $h_{FE} = 15$ (min) at $I_c = 0.01$ ma and $V_c = 5.0V$

These precise transistor assemblies are required in the differential amplifier stages to obtain a properly functioning feedback loop so that very stable output voltage regulation and low ripple can be obtained over a wide range of operating load conditions and temperatures.

The operation of the +15-VDC series regulator can be described briefly as follows:

a. Assume the +15-VDC output increases an incremental amount.

b. A portion of this voltage change is applied to the base of Q4A by means of the resistor divider R3A, R9A, and R10A.

c. This causes an increase in Q4A collector current through R7A which decreases the voltage at the base of Q3A. At the same time, there is a decrease in the collector current through the reference half of Q4A which increases the base voltage on the reference half of Q3A.

d. The base voltage changes in the second differential pair Q3A cause the Q3A collector current through R1A to increase, which decreases the voltage at the base of Q2A.

e. A decrease in Q2A base voltage causes a corresponding decrease in Q1A base voltage. This results in a decrease in Q1A emitter voltage which is the +15-VDC output voltage buss. This decrease cancels the initial incremental output voltage increase.

Operation of the -15-VDC series regulator is exactly the same as that of the +15-VDC regulator described above. The only difference between the two supplies is the method of connection to the missile electrical system for obtaining the correct polarity. In the +15-VDC supply, the emitter of the series transistor Q1A is the +15-VDC distribution buss. In the -15 VDC supply, the emitter of the series transistor Q1 is grounded and the center tap of the transformer secondary winding is the -15-VDC distribution buss.

Resistor R11 and transistor Q5 provide short circuit protection for the -15-VDC supply. The short circuit protection for the +15-VDC supply is provided by R11A and Q5A.

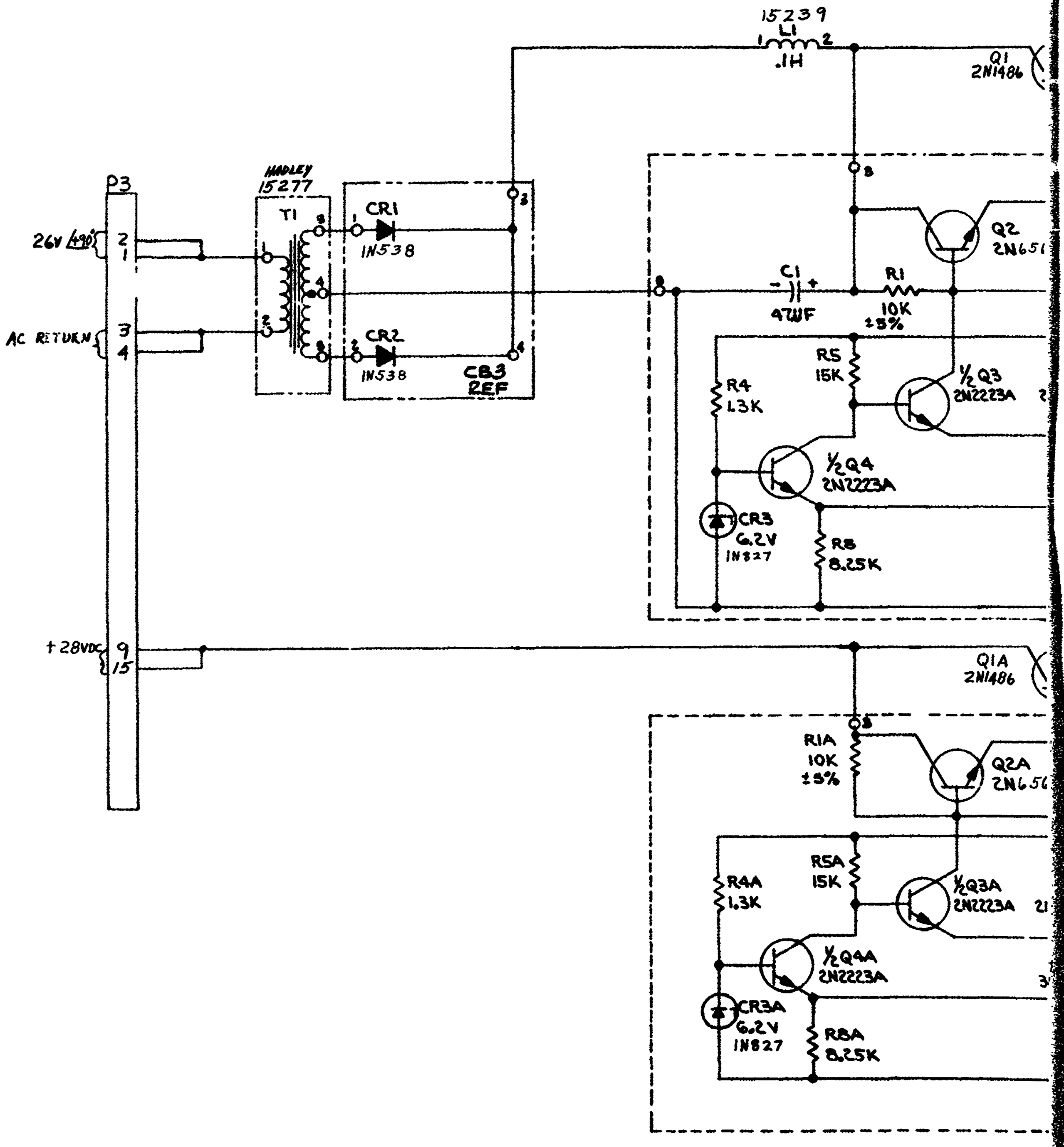

Figure I-2. Schematic, DC Power Supply Subas

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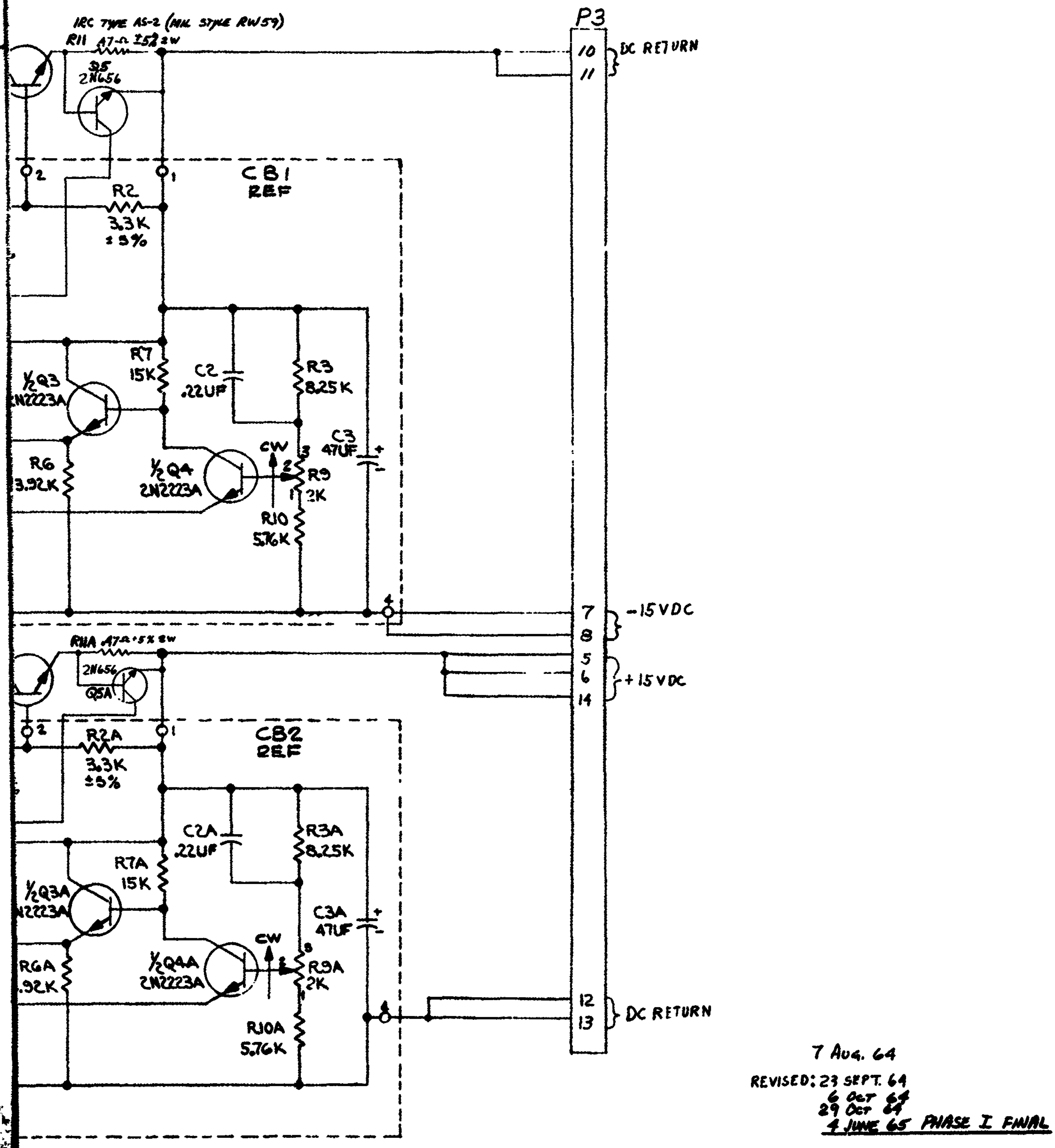


ssembly (Sketch 742-B-20)

C. PROGRAMMER

GENERAL

The programmer subassembly contains all system logic and sequencing required for the IACS. The programmer subassembly includes the necessary logic/timing circuitry for coast-time delay, maneuver-command storage, gyro-torquing, target viewing time, and program sequence control.

A patchboard panel is incorporated in the programmer to provide maximum flexibility with minimum time required for programming. The patchboard panel consists of a printed circuit matrix where the vertical and horizontal strips are on opposite sides of the board. Small screws connect a horizontal and a vertical crossing point to effect a program function.

Program functions that are patched include the sequence, axis, and direction for each maneuver, and the sequence of hold times on each target. Duration of each "hold" is determined by selected fixed resistors. Maneuvers and hold times can be patch-programmed in any sequence desired. The programmer schematic is shown in Figure I-3 and the component layout in Figure I-4.

PROGRAMMER OPERATION

Initial Conditions at power turn-on, in Ledex position 12, are as follows:

a. Coast Time Delay - deactivated

b. "AND" No. 1: Input 1 - grounded

c. "AND" No. 2: Input 3 - grounded
Input 4 - +15 volts

d. "AND" No. 2: Input 1 - grounded
Input 2 - +15 volts

e. Flip-Flop No. 1: Q10 - ON
Q11 - OFF

f. Flip-Flop No. 2: Q15 - OFF
Q16 - ON

g. Flip-Flop No. 3: Q17 - OFF
Q18 - ON

h. Q8 and Q24 - OFF

i. Q4 - hard ON

j. Q12 - hard ON

k. One-Shot Multivibrator: Q6 - OFF
Q7 - ON

l. All relays - as shown

m. Ledex switch - as shown

Activation of the vehicle "g" reduction switch applies +28 VDC to the coil of relay K1, which self-latches and activates the 9 ± 1 second coast time delay circuit. At the completion of the RC-controlled time delay, base 1 of the unijunction transistor Q1 becomes positive and supplies a gate voltage to SCR Q2, thereby actuating relay K2. Relay K2 self-latches and arms the despin and roll control valves by supplying the necessary +28-VDC power. A second function of K2 is the removal of an inhibiting ground to input 1 of "AND" No. 1. This is the first step in the progression of the programmer sequential logic.

The "AND" No. 1 gate has two inputs, the first of which has already been discussed. The other possible inhibitor, input 2, is removed anytime the vehicle is captured in roll as indicated by a positive voltage. When both inputs to "AND" No. 1 are positive, the base of transistor Q3 becomes positive, turning Q3 hard ON. As a result, a positive output voltage appears on the emitter of Q3. The output of "AND" No. 1 is the first of three gate outputs which permit progression of the program sequence. The positive output of "AND" No. 1 applies a bias to the base of two transistor drivers in the IACS control electronics that actuate two self-latching relays, which in turn change the IACS from a rate mode of operation to a position-plus-rate mode, and in addition change the roll rate gain. The positive output of "AND" No. 1 is also used for input 3 of "AND" No. 2.

A positive output for "AND" No. 2, at the emitter of transistor Q5, is achieved in much the same manner as the "AND" No. 1 positive output. Input 4 of "AND" No. 2 is positive whenever gyros are not being torqued by the programmer, and ground when torquing is in progress. When pitch (input 1) and yaw (input 2) capture signals are positive, together with input 3, the output of "AND" No. 2 is positive. The positive output from "AND" No. 2 indicates completion of 3-axis capture. The first 3-axis capture signal produces a pulse which triggers a self-latched SCR that enables the slaved-roll circuits in the IACS control electronics. The positive output of "AND" No. 2 is also used for input 1 of "AND" No. 3.

A positive output for "AND" No. 3 results when input 1 is positive and Q10 of flip-flop No. 1 is hard ON. When Q10 is hard ON, the collector of Q11 is positive, permitting the output of "AND" No. 3 to be positive whenever input 1 is positive. A positive output from "AND" No. 3 provides an input bias for the one-shot multivibrator. A positive input to the base of transistor Q6 turns Q6 hard ON and turns the normally biased ON transistor, Q7, OFF. When Q6 comes ON, its collector voltage drops to near ground potential forcing flip-flop No. 1 transistor Q11 to turn hard ON. When Q11 turns ON, its collector voltage drops to a low level (essentially ground) and is used as an inhibitor to "AND" No. 3, thereby removing the input to the one-shot multivibrator. Flip-flop No. 1 continues to prevent any further inputs to the one-shot multivibrator until initiation of gyro torquing by the actuation of relay K3. When Q6 turns hard ON the state of flip-flop No. 2 is changed such that Q15 turns hard ON and Q16 turns OFF. When Q16 turns OFF, its collector becomes positive, which provides input bias for transistor Q8; therefore Q8 and Q24 turn ON, activating K7 and unshorting the "hold time delay" capacitor in the feedback loop of the differential amplifier.

Also, while Q6 is hard ON, the normal positive bias on the base of transistor Q12 is removed and its collector becomes positive. The positive collector of Q12 provides bias for a Darlington compound (Q13 and Q14) driver. The positive bias turns Q13 and Q14 hard ON, lowering their collectors to near ground level, which advances the ledex switch one position.

The collector of Q6 remains in the state described above for approximately 100 milliseconds; then Q7 returns to its normal ON state which turns Q6 OFF. The input bias to Q12 is thereby re-applied, turning Q12 hard ON, and turning Q13 and Q14 OFF, which relaxes the ledex.

When the ledex is advanced, ledex deck No. 2 applies +15 VDC to the "hold time delay" circuit. This +15 VDC can be applied either through a selected time delay resistor or directly to the hold time delay circuit. When applied directly, only 500 milliseconds elapse before an output occurs from Q9. For a more detailed description of the Hold Time Delay, see Section O of this appendix.

When the hold time delay is completed, base 1 of the unijunction transistor Q9 becomes positive, which changes the state of flip-flops No. 2 and No. 3. When the state of flip-flop No. 2 changes, the collector voltage of Q16 drops, removing the input bias to Q8, thereby reinstating the short across the hold time delay capacitor by turning Q8 and Q24 OFF. Q8 and Q24 remain OFF until the next ledex advance pulse from the one-shot multivibrator. When flip-flop No. 3 changes state, the collector of Q18 becomes positive, providing input bias for the Q19-Q20 Darlington compound driver. The positive input bias turns Q19 and Q20 hard ON, thereby actuating relay K3 which initiates gyro torquing.

The functional logic of relays K3, K4, K5, K6, and K8 is as follows:

<u>K3</u> Deactivated: Maneuver torquing <u>is not</u> in progress.

a. Applies +15 VDC to input 4 of "AND" No. 2.

b. Turns transistor Q4 hard ON, removing input bias to flip-flop No. 1 transistor Q10.

c. Shorts the integrating capacitor in the variable time torquing circuit.

d. Applies 26 V $\underline{/0^\circ}$ and 26 V $\underline{/+90^\circ}$ to the SACS control electronics.

Actuated: Maneuver torquing in progress.

a. Applies an inhibiting ground to input 4 of "AND" No. 2, preventing progression of program sequence until completion of maneuver torquing.

b. Turns transistor Q4 OFF, thereby changing the state of flip-flop No. 1 by turning Q10 hard ON, which applies a positive voltage to input 2 of "AND" No. 3, permitting progression of the program sequence when roll-pitch-yaw capture has once again been satisfied.

c. Unshorts the integrating capacitor in the variable time torquing circuit.

d. Removes the 26 V $\underline{/0^\circ}$ and 26 V $\underline{/+90^\circ}$ to the SACS control electronics.

e. Applies maneuver torquing voltages to the contacts of relay K4.

K5 Deactivated: Applies CW maneuver torquing voltages to the voltage and current monitors of the variable time torquing circuit.

Actuated: Actuated only when a CCW maneuver is desired. Applies CCW maneuver torquing voltages to the voltage and current monitors of the variable time torquing circuit.

K6 Deactivated: Signifies that the maneuver axis is roll.

a. Applies maneuver torquing voltages to the roll gyro inner gimbal torquer motor control and reference windings.

b. Grounds input to inner gimbal gyro compensation network (diode function generator).

Actuated: Signifies that the maneuver axis is either pitch or yaw.

a. Applies maneuver torquing voltages to the contacts of relay K8.

b. Applies input to inner gimbal gyro compensation network from contacts of relay K8.

K8 Deactivated: Signifies that the maneuver axis is either roll or pitch.

a. If K6 has been actuated, K8 applies maneuver torquing voltages to the roll gyro outer gimbal torquer motor control and reference windings.

b. Applies the pitch position synchro signal to the contacts of K6.

Actuated: Signifies that the maneuver axis is yaw. K6 is also actuated.

a. Applies maneuver torquing voltages to the slaved roll gyro outer gimbal torquer motor control and reference windings.

b. Applies the yaw position synchro signal to the contacts of K6.

K4 Caging Relay
Deactivated: Applies +28 VDC to the coil of relay K3.

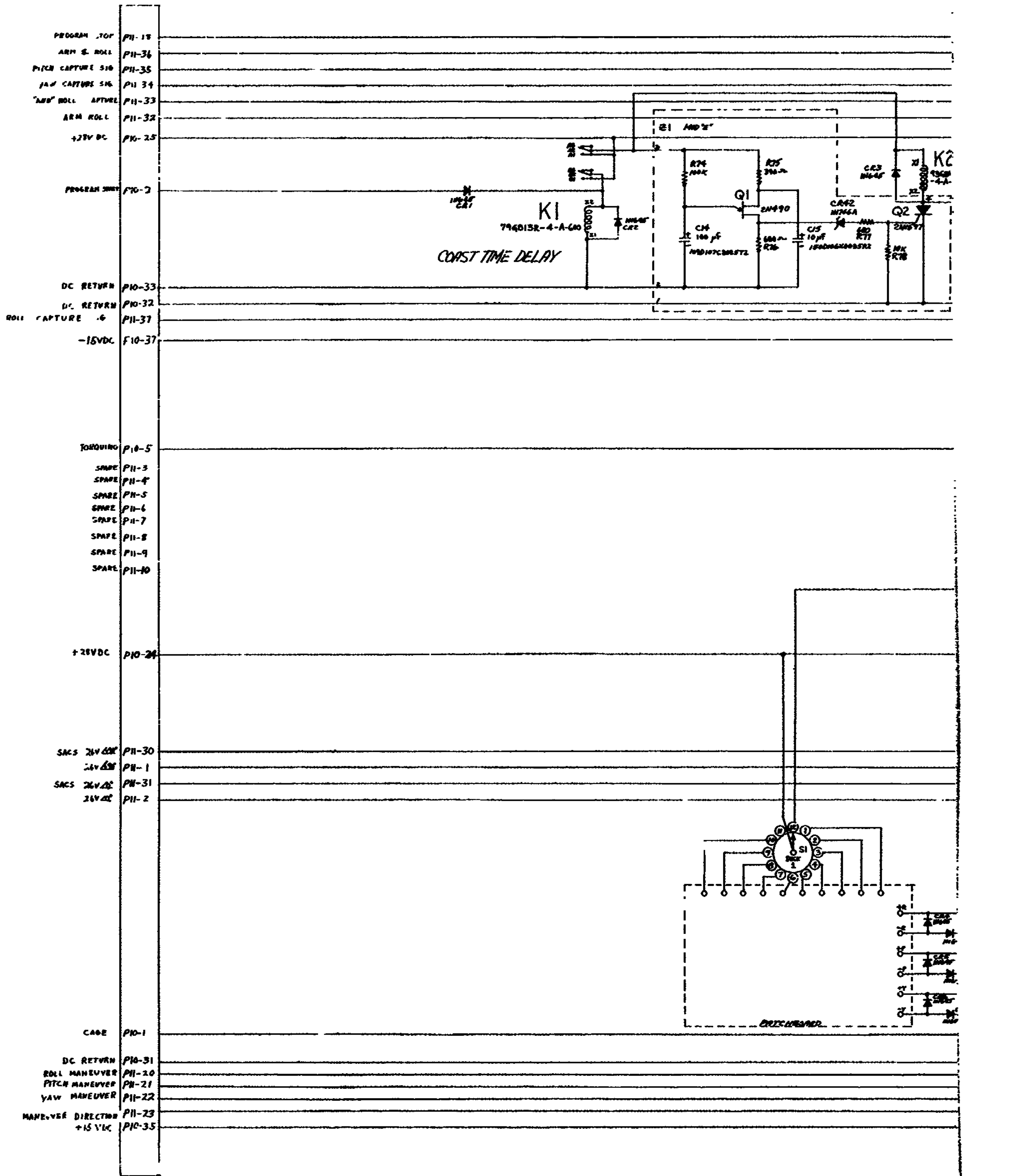
Actuated: Removes +28 VDC from coil of relay K3, preventing maneuver torquing of the gyros, and applies +15 VDC to flip-flop No. 3, turning Q18 hard ON if K4 is actuated while maneuver torquing was in progress. (This latter requirement is for ground test only.)

Whenever K3 is actuated, a gyro will be precessed through some selected angle. The currents applied to the gyro torquer motor windings are monitored by two current transformers, one for each torquer winding, and applied at a weighted level to the integrating operational amplifier. The torquing voltages are monitored, weighted, and applied, along with a positive constant voltage, to the integrator. Integrating these weighted terms compensates, by altering the torquing time, for variations in torquing voltage as well as for variations in current drawn by the torquer motor windings due to temperature changes.

The integrator output is compared with a reference voltage applied for each program position. There are ten reference voltage potentiometers allowing for five 2-axis maneuvers to be programmed.

When the outputs of the integrator and the reference voltage are of equal magnitude and opposite polarity, the differential amplifier Q21 actuates the Q22-Q23 Schmitt-type trigger. As a result, the normally ON transistor, Q23, turns OFF and its collector becomes positive. This positive signal is applied to flip-flop No. 3 (the base of Q18) which turns Q18 hard ON, removing the input bias to Q19. Q19 and Q20 turn OFF, deactivating relay K3, which stops the gyro torquing. To continue the program, 3-axis capture must occur, thereby advancing the ledex one more position.

When making a maneuver in either pitch or yaw, the respective position synchro signal is applied to the diode function generator. The diode function generator output is applied to the variable time torquing circuit integrator to compensate for inner gimbal lag angles when torquing in pitch or yaw.


PROGRAM STOP P11-18
ARM & ROLL P11-36
PITCH CAPTURE SIG P11-35
P11 34
ROLL P11-33
ARM ROLL P11-32
P10-25
P10-2
K1
COAST TIME DELAY
Q1
2N490
Q2
K2
DC RETURN P10-33
DC RETURN P10-32
ROLL CAPTURE P11-37
-15VDC P10-37
TORQUING P10-5
SPARE P11-3
SPARE P11-4
SPARE P11-5
SPARE P11-6
SPARE P11-7
SPARE P11-8
SPARE P11-9
SPARE P11-10
+28VDC P10-24
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P11-1
SACS P11-31
P11-2
S1
CAGE P10-1
DC RETURN P10-31
ROLL MANEUVER P11-20
PITCH MANEUVER P11-21
YAW MANEUVER P11-22
MANEUVER DIRECTION P11-23
+15 VDC P10-35

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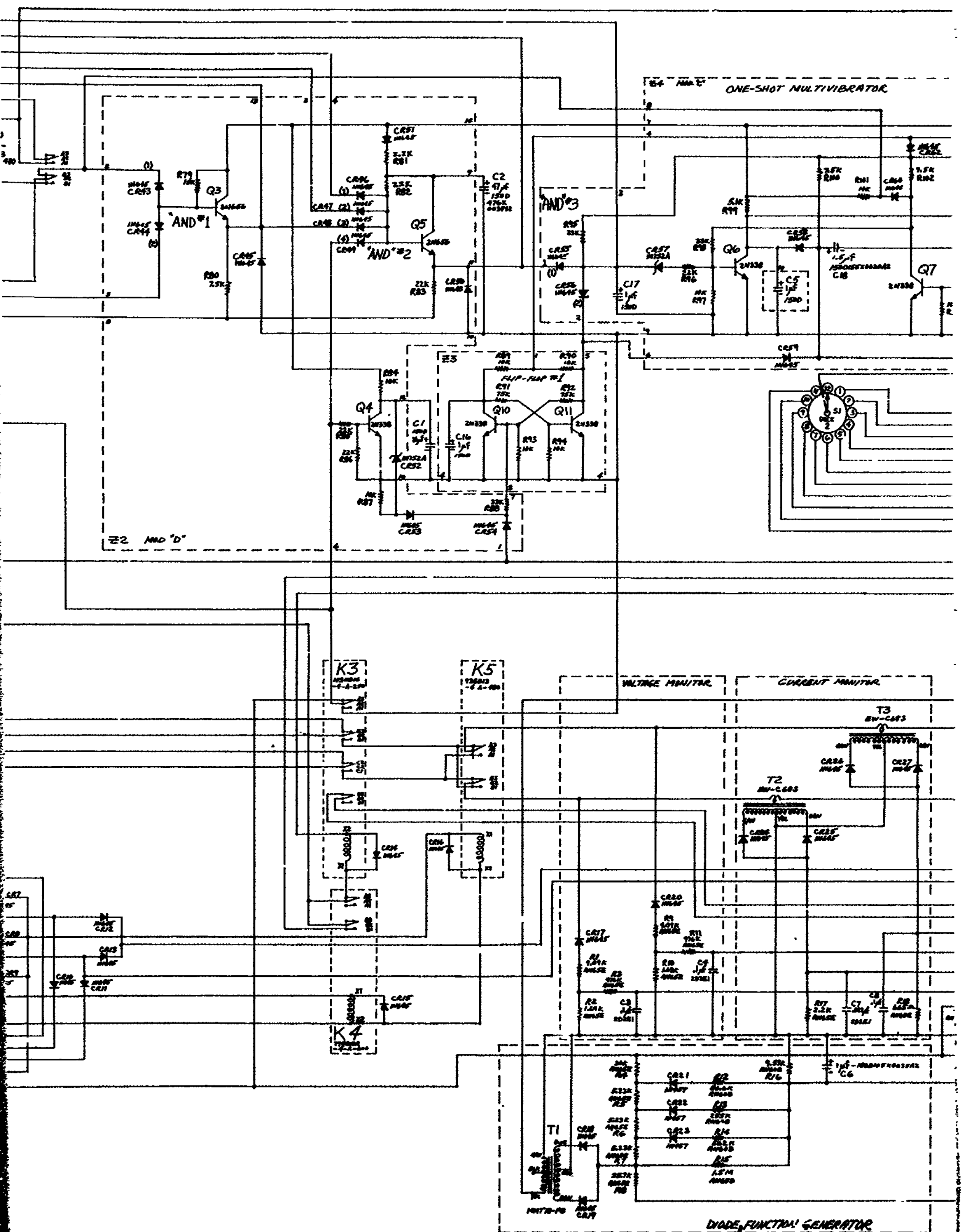
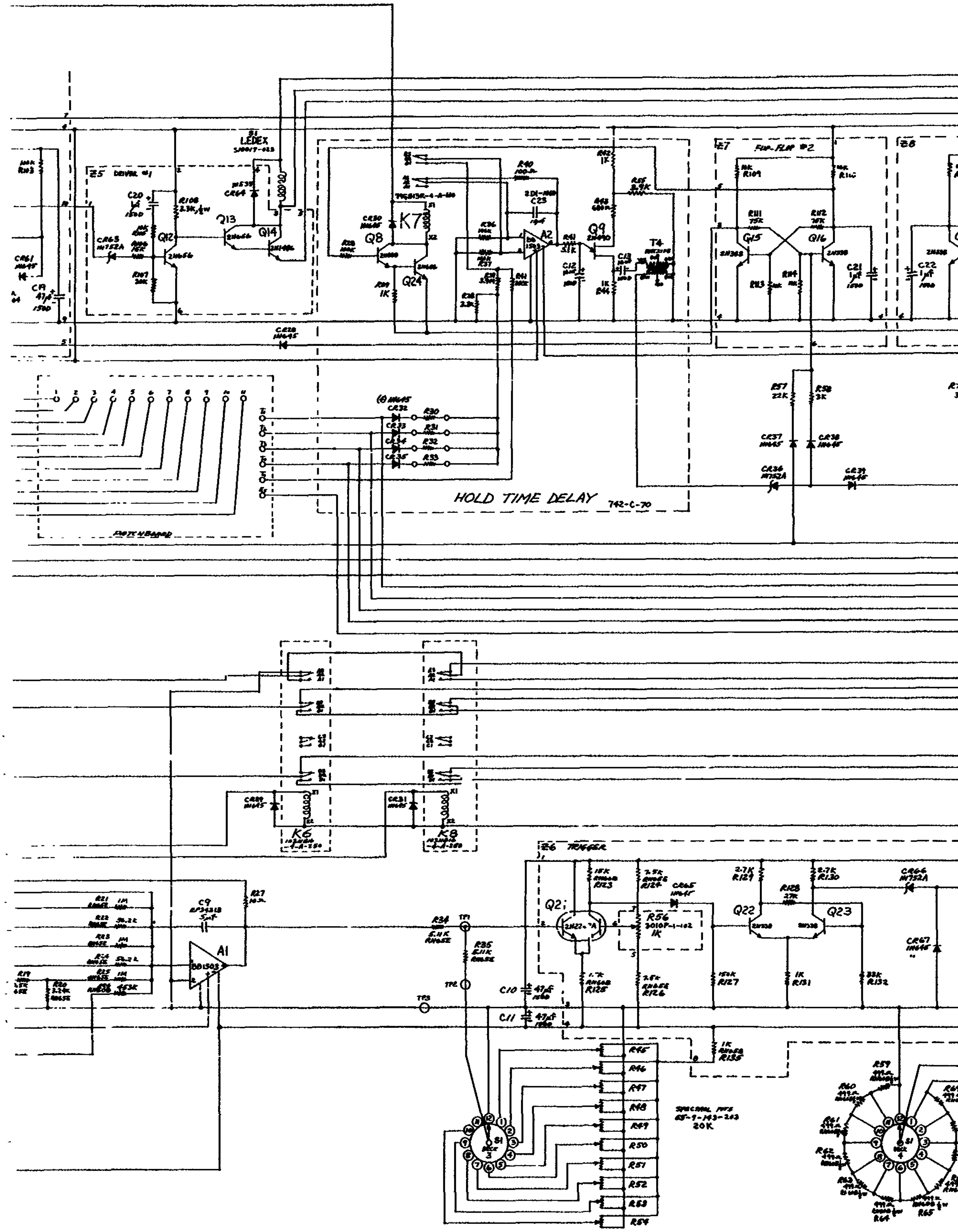
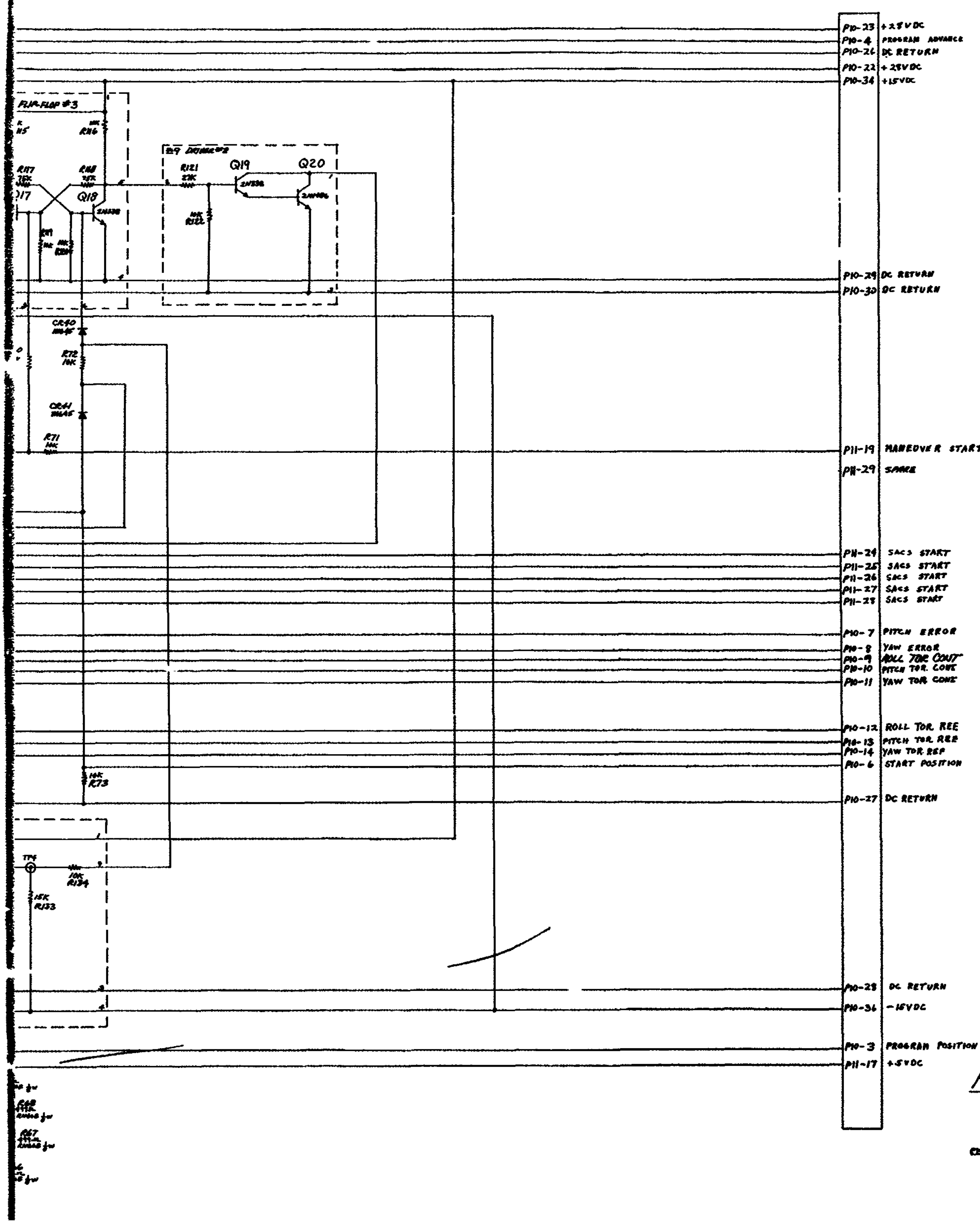


Figure I-3. Schematic, Pro



grammer Subassembly (Sketch 742-B-30)

I-18 (3)



742-B-30

PROGRAMMER

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15 Jan 1965
10 FEB 1965
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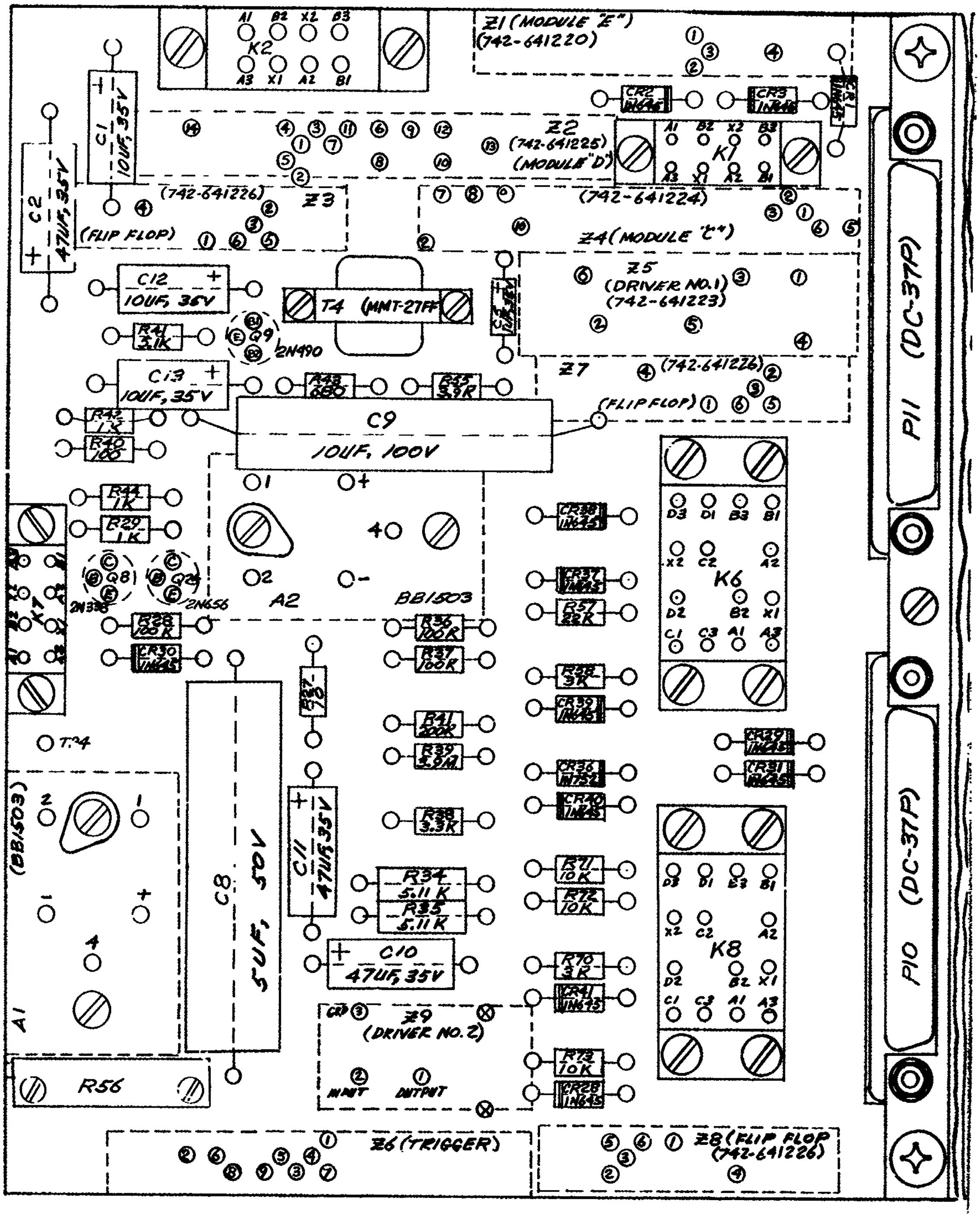
4 June 65 PHASE I FINAL



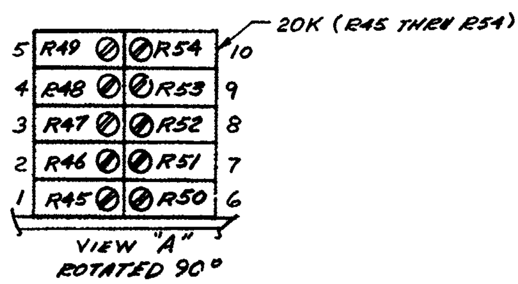
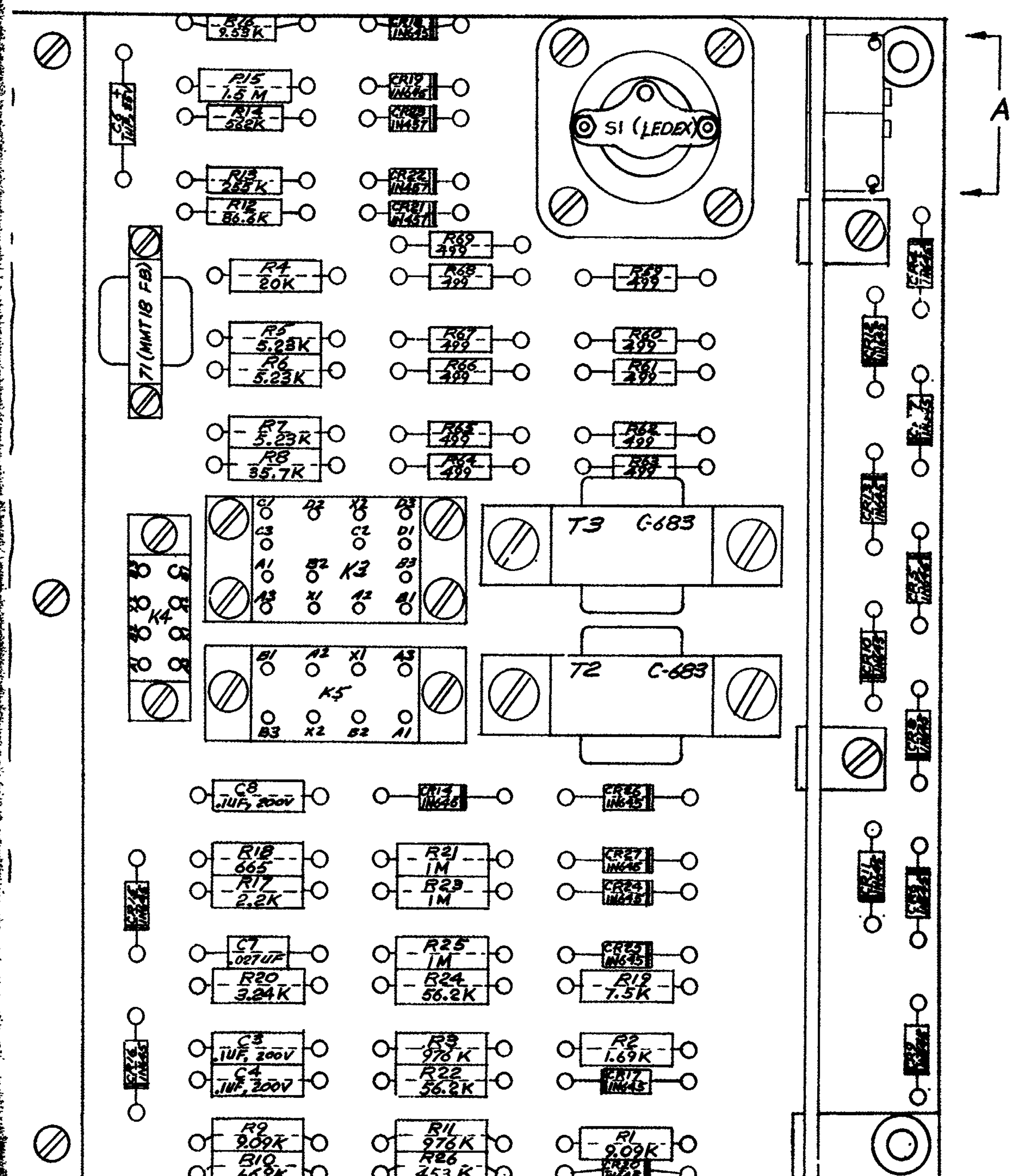


Figure I-4. Layout,Programmer S



ubassembly (Sketch 742-641214)

D. IACS CONTROL ELECTRONICS

GENERAL

The IACS control electronics subassembly contains the IACS roll, pitch, yaw, and slave roll control channels as well as the IACS roll, pitch, and yaw capture detectors. A schematic diagram of the IACS control electronics subassembly is shown in Figure I-5 and the component layout in Figure I-6.

PITCH CHANNEL

The pitch control channel accepts two gyro inputs: the pitch position error signal from the pitch position gyro, and the pitch rate error signal from the pitch rate gyro.

Pitch position error voltages are applied single ended to the primary winding of a Microtran Co., Inc., MMT-27FB step-up transformer. The transformer secondary is center-tapped and has a step-up ratio of 1 to 3.23 from full primary to the center tap. Transformed error voltage is applied to the input terminals of a phase-sensitive full-wave demodulator and also returned to the junction box. Gyro output signals are 400-cps voltages which are either in phase or 180° out of phase with the static inverter 0° phase. Since the demodulator is referenced to 0° phase it converts its input signal to an 800-cps full-wave rectified voltage having an average DC value either positive or negative depending on the phase relationship to the reference. The demodulator output voltage is fed via a 22K isolation resistor to the junction box for telemetry. The full-wave rectified demodulator output is filtered by a 2-section RC filter. Each section consists of a 10K series resistor and a 1-µf shunt capacitor.

Gyro error level detection has two possible modes of implementation in the breadboard system. The pitch error signal is applied to the input of an AC amplifier (Burr Brown 1503) whose output is returned to the junction box. The mode of operation of level detection is determined by jumper selection in the junction box. Connection thru the amplifier (P12-24 jumpered to P12-23 in the junction box) provides gain before being applied to an absolute value circuit which activates a half trigger, Figure I-20, at an error voltage corresponding to 0.40°. Connection directly from the MMT-27 FB secondary (P12-22 jumpered to P12-23 in the junction box) provides trigger activation at 2.0°. Trigger activation is termed pitch capture.

The output of the absolute value/half trigger combination actuates relay K1 through a Darlington-connected two-transistor relay driver. It also is sent to the junction box (P12-4) to provide a pitch capture signal to the programmer. Relay K1 serves to remove the short around one of the series resistors which determine the rate gain of the pitch channel. A signal to telemetry (28 VDC) at pitch capture is delivered by K1 also (P13-33).

Pitch rate gyro output (P12-20) is applied to a buffer amplifier to present a constant impedance load to the rate gyro synchro. It is then voltage amplified by the MMT-27 FB transformer and demodulated in precisely the same manner as the position error signal.

Both the pitch rate gyro and position gyro outputs (after demodulation and filtering) are resistively summed at the input to a Burr Brown 1503 operational amplifier. To prevent saturation of the DC amplifier, biased diodes (1N457 and voltage divider of 8.2K and 820 Ω) clip the amplifier output at about 2.0 volts. The 3-megohm feedback resistor and the rate and position summing resistors accurately determine the DC gain of the operational amplifier. See Figure 4 for block diagram of pitch axis scaling of IACS and SACS. A capacitor in parallel with the feedback resistor provides additional filtering at the output of the amplifier.

The output of the operational amplifier can be positive or negative depending on the amplitudes and polarities of the operational amplifier inputs. This output is connected to the input of a full trigger, Figure I-19. This network contains two identical trigger channels designed to trigger at 1 volt. A positive input signal triggers one channel while a negative signal triggers the other. Each trigger channel drives a Darlington-connected pair of transistors (2N656 and 2N1486) which control the operation of the pitch CW and CCW valves. The Darlington valve driver collectors are connected to +28 VDC through the junction box and in series with the proper pitch valve solenoids. The driver emitters find ground through a 1N1124A blocking diode and relay K7 in the roll control channel. Relay K7 is enabled and latched by the action of the roll CCW driver which places a ground at the relay coil. Enabling of K7 occurs at the end of despin. The foregoing logic permanently enables the pitch channel. It is also possible to conditionally enable the pitch drivers by activating relay K6 and K8 from the GSE through P12-8. Relay K6 places ground on the driver emitters and simultaneously removes the +28 VDC from the valves. DC voltage is applied in the GSE through indicator lights to the driver collectors. Relays K6 and K8 then allow the status of the pitch channel drivers to be monitored during caging without valve actuation. Relay K9 is used to keep the pitch position error input to the summing point of the operational amplifier at ground. This permits pitch channel operation in a <u>rate only</u> mode during roll capture after despin valve turnoff. Relay K9 is activated through a relay driver (2N656) by the roll capture logic signal. Self-latching of K9 may be accomplished by jumpering P12-30 and P12-31 in the junction box.

YAW CHANNEL

The yaw control channel is identical to the pitch channel. The yaw channel processes the position error signal from the yaw position gyro, and the rate error signal from the yaw rate gyro. As in the pitch channel, the yaw channel provides the following:

a. A yaw position demodulator output signal for data transmission in the telemetry system.

b. A filtered yaw position demodulator output signal for the SACS system.

c. A yaw capture output signal for use in the programmer.

d. A yaw capture logic output signal for data transmission in the telemetry system.

As in the pitch control channel, there is provision for decreasing the rate gain of the yaw control channel when a condition of yaw capture has been attained.

The pitch channel description also describes the action of the yaw channel.

ROLL CHANNEL

The roll channel is identical to pitch and yaw channels with the following exceptions:

a. Relay K3 used to change rate gain at roll capture may be latched if P12-28 and P12-29 are jumpered in the junction box. Normally K3 will be energized by the roll capture signal applied to P12-6. A 2N656 relay driver actuates the relay. This roll capture signal is also used to operate relay K9 in the pitch and yaw channels as previously described. A 28-VDC signal to telemetry signifying roll capture is also provided through K3.

b. Relay K7 is used to disable the large despin valve at the end of despin and enable the normal roll CW control valve. Completion of the coast time delay applies 28 VDC to P12-7. In the de-energized state K7 permits actuation of the despin valve (P12-17) and the roll CCW (P12-14) valve. However, only the despin valve driver is energized because of the fixed sense of the vehicle spin rate.

Upon reduction of the vehicle spin rate to the point where the opposite (CCW) valve is actuated (corresponding to intersection of the phase plane switching line), a ground is applied to the K7 coil through a 1N645 blocking diode and the CCW driver transistor. This allows K7 to be energized and latched through its own contacts.

SLAVE ROLL CONTROL CHANNEL

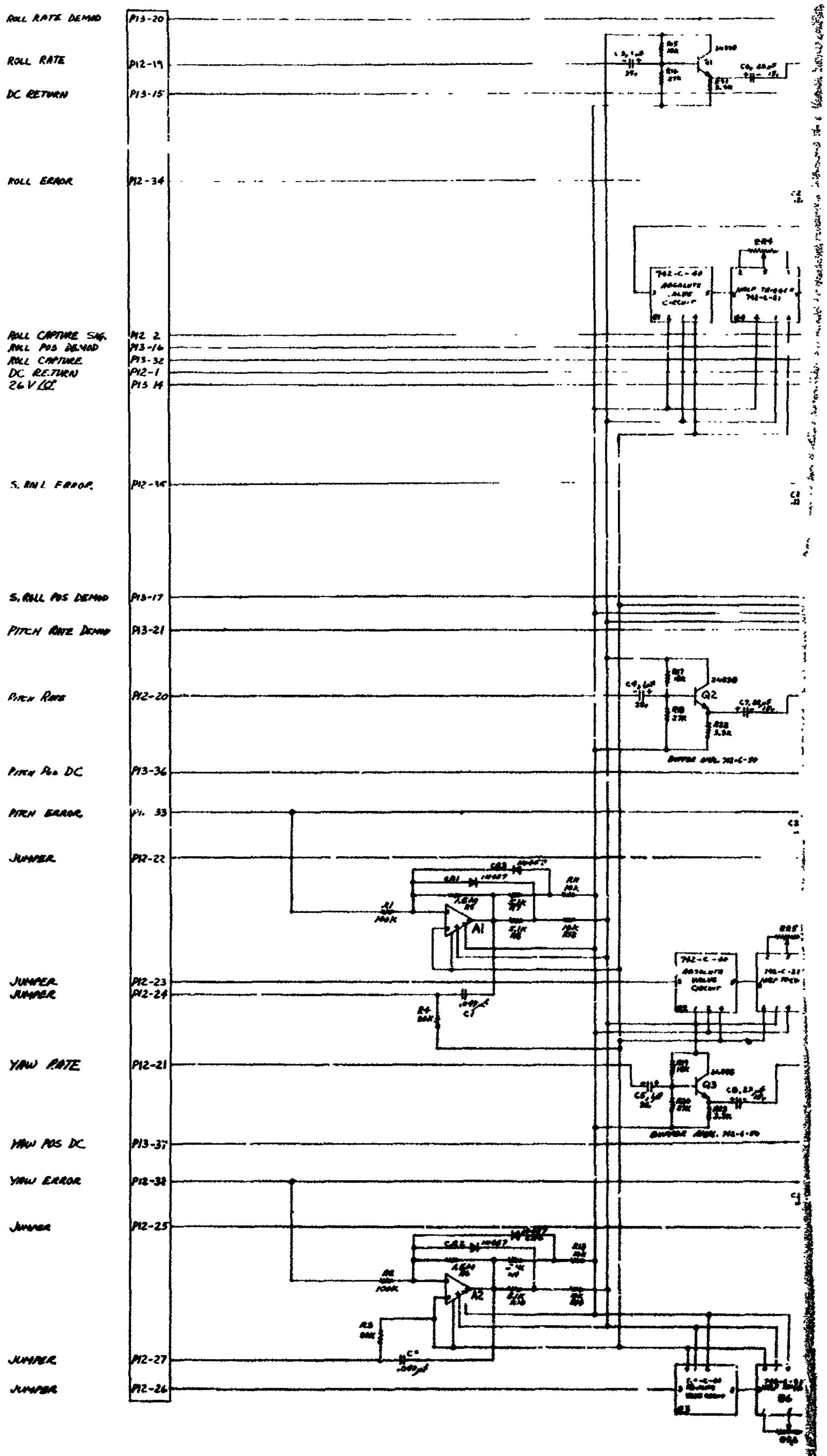
The slave roll control channel processes the position error signal from the slave roll gyro for controlling the phasing of the control and reference voltages which torque the slave roll gyro to a null position.

The position error output from the slave roll gyro is applied to an input transformer similar to the pitch and yaw channels. The full-wave rectified output of the demodulator is filtered by a 1-μf capacitor to ground. The demodulator output is sent to the telemetry system through a series resistor which prevents loading the demodulator output in the event of a possible failure in the telemetry system. The demodulator output is applied to the input of a full trigger circuit through an operational amplifier with a gain of 7. One trigger channel is activated by a positive input signal, while the other triggers on a negative input.

The outputs of the two trigger channels in the full trigger network each drive a pair of relay driver output transistors. For a given input polarity to the full trigger network, one pair of output driver transistors and its associated relay (K4) are energized, thereby applying the 26 volt rms$\angle 90^{\circ}$ static inverter phase to the control winding and the 26 volt rms$\underline{/0^\circ}$ phase to the reference winding in the torquer section of the slave roll gyro. A full trigger input signal with the reverse polarity causes the other transistor pair and associated relay K5 to become energized, thereby reversing the phasing to the reference and control windings in the slave roll gyro.

The emitters of the 2N656 output driver transistors are connected to a 2N2323 SCR gating circuit. The SCR is effectively an open circuit until an arm slave roll input signal is received. This signal is generated when pitch, yaw and roll capture have been attained simultaneously. The arm slave roll input signal is applied to an input network at the gating terminal of the SCR. This network contains a biasing circuit which applies a negative hold-off potential to the gating terminal of the SCR. The biasing circuit contains a diode which clamps the negative hold-off potential to approximately 0.6 volt. The hold-off potential guarantees that the SCR will not trigger due to spurious transients or operation at high temperatures. This circuit also contains a filter capacitor which provides additional protection for bypassing spurious transient voltages on this line which might inadvertently trigger the SCR. The SCR is shorted through P12-18 by the GSE when caging.

Another output is sent to the GSE console, which indicates when the slave roll control channel is at null (P12-9). This is done by connecting a set of "back" contacts on each relay (in series) to the 26 volt rms$\underline{/0^\circ}$ static inverter phase. At null the slave roll null output line is connected to the 26 volt rms supply through the contacts. If either relay is energized when the slave roll system is not at null, the circuit is interrupted.


ROLL RATE DEMOD
P13-20
ROLL RATE
P12-19
DC RETURN
P13-15
ROLL ERROR
P12-34
ROLL CAPTURE SIG.
P12 2
ROLL POS DEMOD
P13-16
ROLL CAPTURE
P13-32
DC RETURN
P12-1
26 V
P13 14
S. ROLL POS DEMOD
P13-17
PITCH RATE DEMOD
P13-21
PITCH RATE
P12-20
Q2
PITCH POS DC
P13-36
PITCH ERROR
JUMPER
P12-22
A1
JUMPER
P12-23
JUMPER
P12-24
YAW RATE
P12-21
Q3
YAW POS DC
P13-37
YAW ERROR
JUMPER
P12-25
A2
JUMPER
P12-27
JUMPER
P12-26

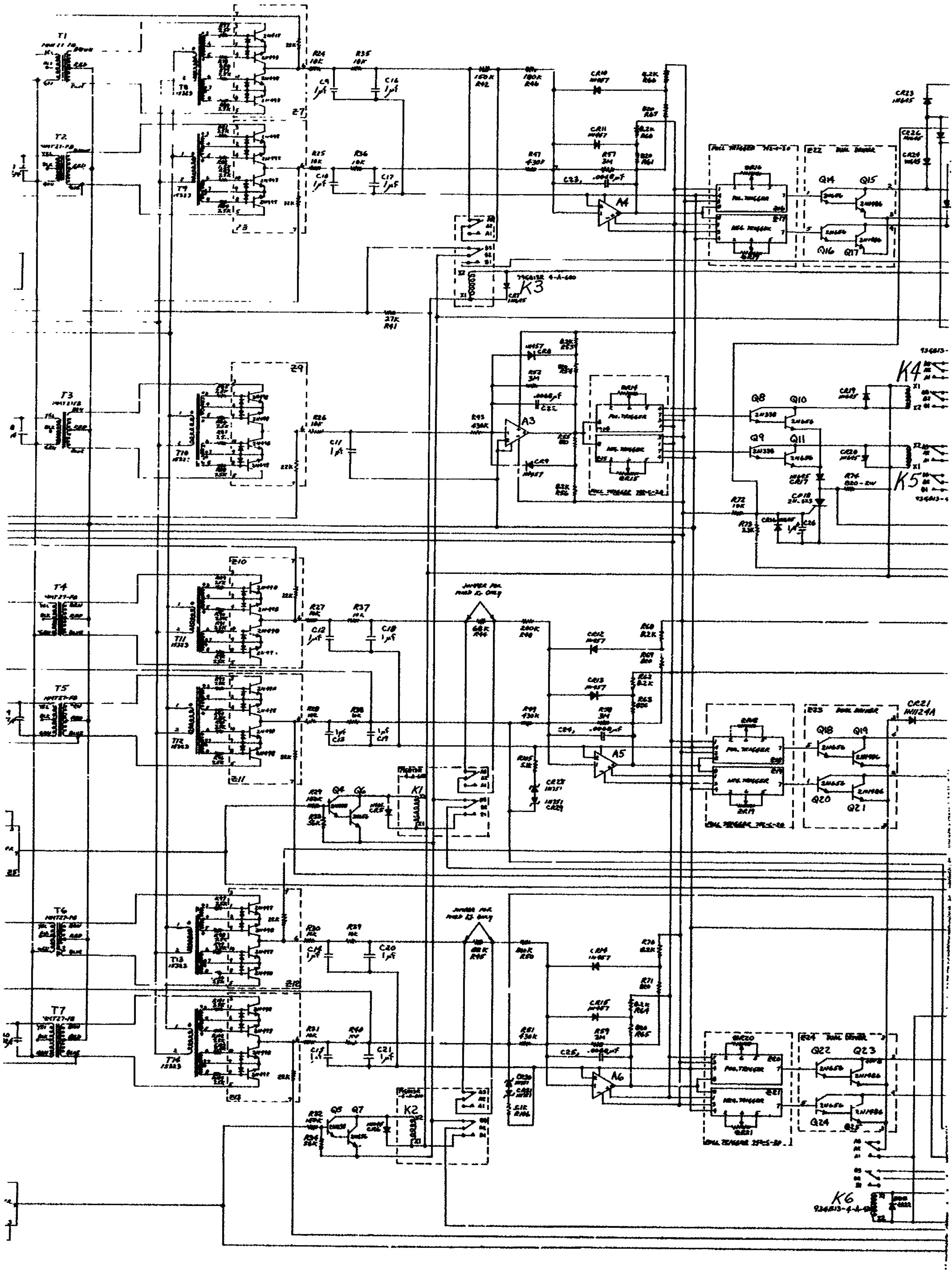
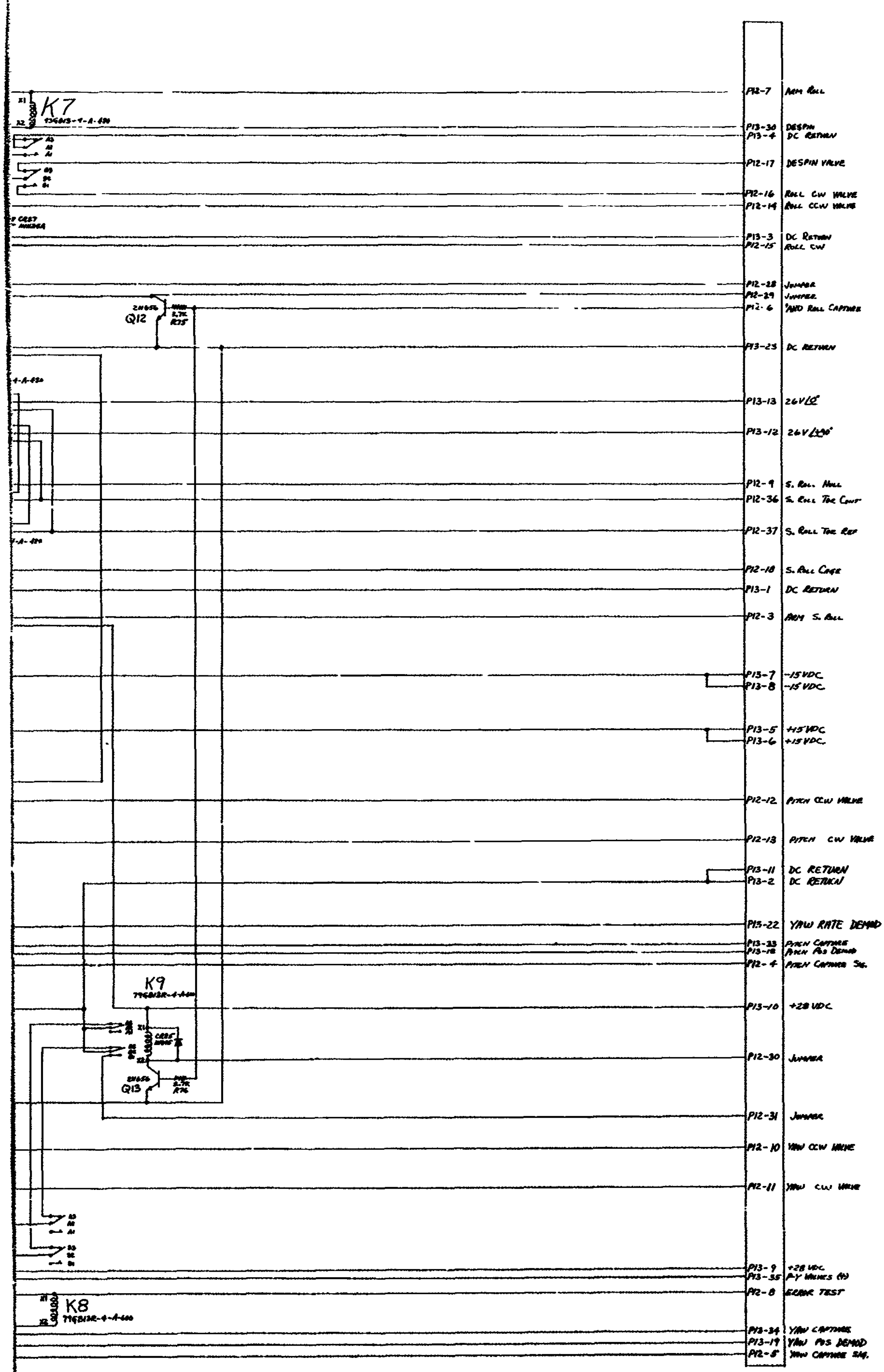


Figure I-5. Schematic, IACS Control Electronics Subassembly
(Sketch 742-B-40)

I-25


K7
Q12
R75
K9
CR25
Q13
R76
K8
P12-7 ARM ROLL
P13-30 DESPIN
P13-4 DC RETURN
P12-17 DESPIN VALVE
P12-16 ROLL CW VALVE
P12-14 ROLL CCW VALVE
P13-3 DC RETURN
P12-15 ROLL CW
P12-28 JUMPER
P12-29 JUMPER
P12-6 AND ROLL CAPTURE
P13-23 DC RETURN
P13-13 26V∠0°
P13-12 26V∠±90°
P12-9 S. ROLL NULL
P12-36 S. ROLL TOR CONT
P12-37 S. ROLL TOR REF
P12-18 S. ROLL CAGE
P13-1 DC RETURN
P12-3 ARM S. ROLL
P13-7 -15VDC
P13-8 -15VDC
P13-5 +15VDC
P13-6 +15VDC
P12-12 PITCH CCW VALVE
P12-13 PITCH CW VALVE
P13-11 DC RETURN
P13-2 DC RETURN
P13-22 YAW RATE DEMOD
P13-33 PITCH CAPTURE
P13-18 PITCH POS DEMOD
P12-4 PITCH CAPTURE SIG.
P13-10 +28 VDC
P12-30 JUMPER
P12-31 JUMPER
P12-10 YAW CCW VALVE
P12-11 YAW CW VALVE
P13-9 +28 VDC
P13-35 P-Y VALVES (+)
P12-8 ERROR TEST
P13-34 YAW CAPTURE
P13-19 YAW POS DEMOD
P12-5 YAW CAPTURE SIG.

3

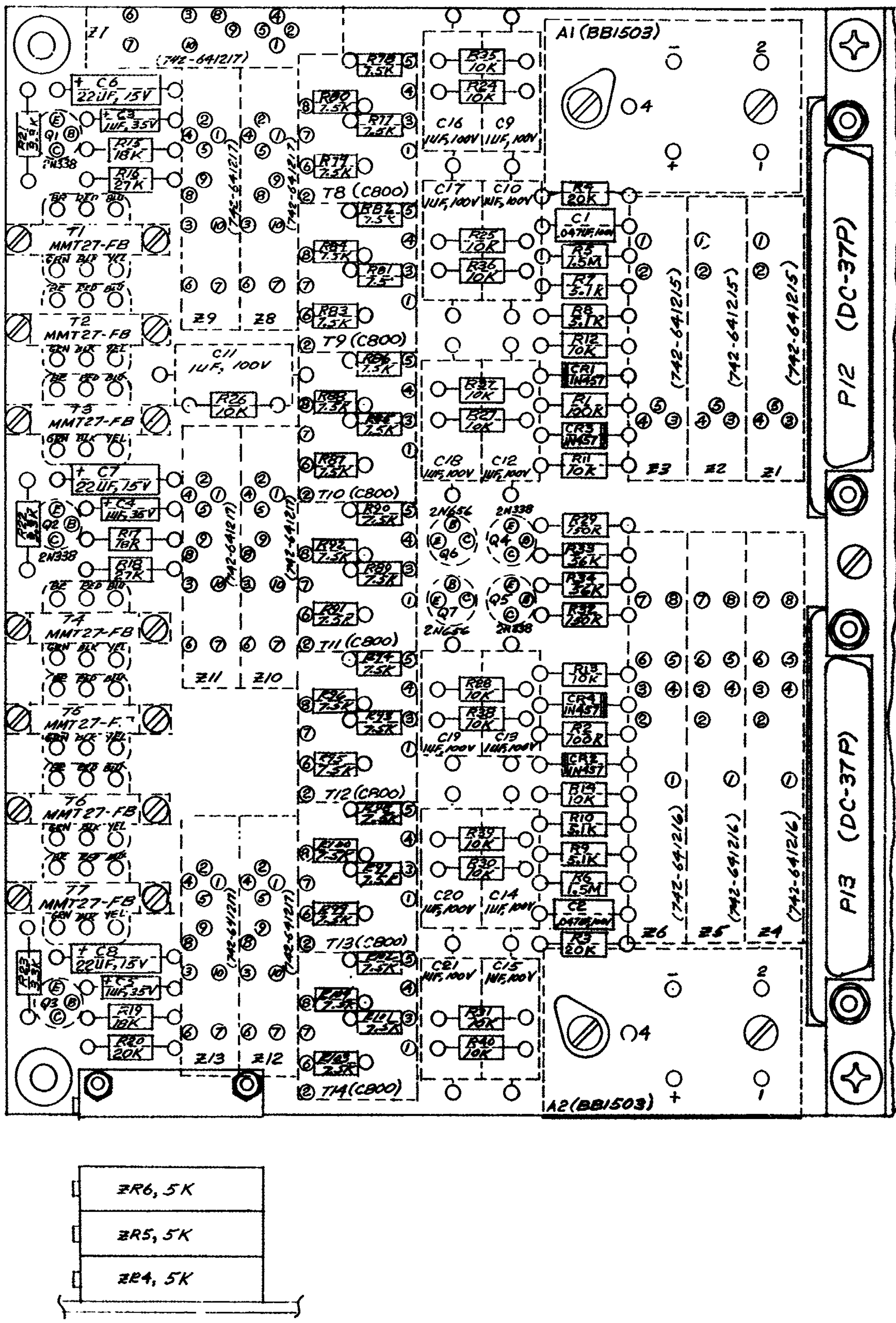
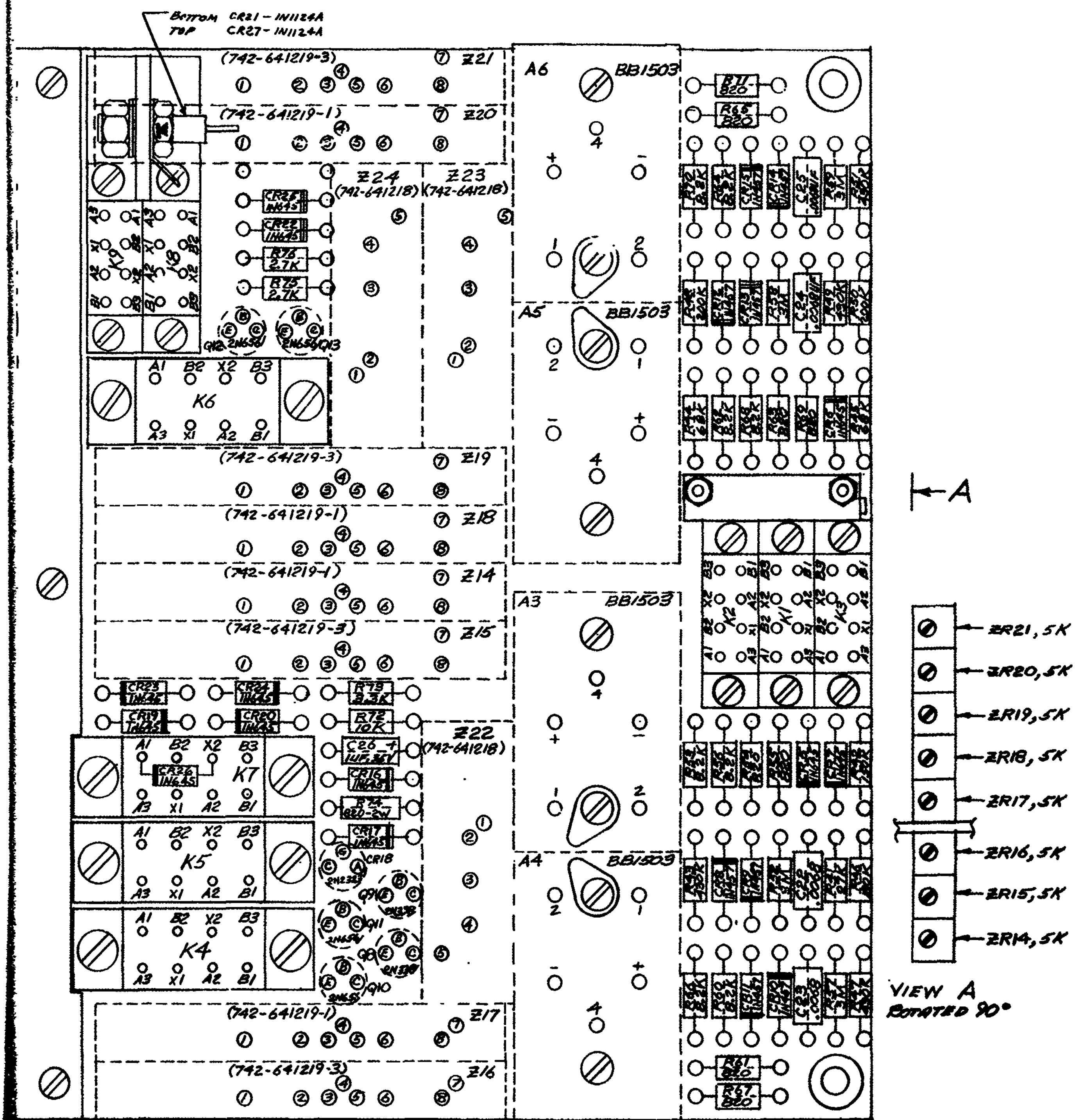


Figure I-6. Layout, IACS Control Elec



tronics Subassembly (742-641207)

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E. SACS CONTROL ELECTRONICS

GENERAL

The SACS control electronics subassembly contains the SACS pitch and yaw control channels, gyro torquing channels, position error level detector channels, as well as the time delays and logic circuitry required for SACS operation. A schematic diagram of the SACS control electronics is shown in Figure I-7 and the component layout in Figure I-8.

The SACS control circuits for pitch and yaw are identical. The output signal from the solar sensor is applied to the input of a DC operational amplifier which is connected to provide lead-lag characteristics to the amplified sensor signal. The amplifier output is directed to trigger circuits which control the action of a pair of Darlington compound driver circuits. The drivers are connected in series with the SACS control valves. Operation of a driver completes the ground circuit for one valve.

The SACS gyro torquing channels for pitch and yaw are identical in design. The output signal from the solar sensor is summed with the demodulated position gyro output signal at the input to a DC operational amplifier. The amplifier output is directed to trigger circuits which control the action of a pair of Darlington compound driver circuits. The drivers are connected in series with the gyro torquing relays, K2, K3 and K7, K8. Operation of a driver completes the ground circuit for one torquing relay. The relay contacts are wired to provide appropriate 26 VAC phase to the control and reference windings of the position gyro torquers.

Pitch and yaw have identical gyro position error level detector circuits. The output signal from the position gyro is amplified by an AC amplifier (Burr Brown 1503), rectified, and applied to a half-trigger. When the rectified signal is below a level corresponding to a gyro position error of 0.4°, the half trigger provides a positive output voltage.

The timer and logic circuits provide for enabling the SACS and for automatically transferring control from the IACS to the SACS. Flip-flop No. 4 receives signals from the programmer which enable the SACS circuits at the start of a hold period and disable them upon start of gyro torquing. "AND" No. 4 provides an output which starts time delay No. 1. This time delay in conjunction with time delays No. 2P and No. 2Y (pitch and yaw, respectively) provide outputs which control the progression of changeover to SACS control.

Caging relays K9 and K10 are operable from the GSE. Energization of these relays isolates the SACS torquing relays from the gyro torquers and permits application of voltage to the pitch and yaw gyro torquers from the GSE.

OPERATION

The SACS circuits are inactive at all times except when SACS operation is desired during an IACS holding period. In the FACS starting position (ledex position No. 12), flip-flop No. 4 is held in a state where transistor Q17 is conducting. The collector of Q17 is at a low voltage and thus input 1 to "AND" No. 4 is near ground potential. Without this input, SACS operation is prevented.

A change in state of flip-flop No. 4 occurs when the programmer ledex switch advances into a position wherein a hold period is programmed. As the ledex advances, +15 VDC will appear at one of the inputs P14-9 through -13. The application of this voltage to a pulse generator results in a positive pulse to flip-flop No. 4. This will change the state of flip-flop No. 4 and cut off Q17. With Q17 cutoff, a positive voltage is applied at input 1 of "AND" No. 4 and at the base of transistor Q16. Thus the first necessary condition for "AND" No. 4 is present, and the Darlington driver (Q16, Q15) is enabled.

Operation of time delay No. 1 occurs when the following inputs are present at "AND" No. 4.

a. Flip-flop No. 4 has Q17 cutoff and a resultant positive voltage appears at input 1.

b. The absolute value of both pitch and yaw gyro output signals are lower than the level established by the half-triggers and a resultant positive voltage appears at inputs 2 and 3, respectively.

In the breadboard FACS, inputs 2 and 3 to "AND" No. 4 may be provided in two ways. The SACS control unit incorporates, for both pitch and yaw, the necessary circuits for level detection of the position gyro outputs. In yaw, the position gyro output is applied to an AC amplifier, rectifier, and filter, and applied to a half-trigger. The half-trigger output P14-35 can be jumpered to P14-36, thus providing input 3 to "AND" No. 4. Alternatively, the IACS half trigger output can be jumpered to P14-36. The objective of this configuration is to permit evaluation of both the "single-level detector" and "dual-level detector" approaches.

Time delay No. 1 is activated when positive voltages are present at the three inputs of "AND" No. 4. This condition permits charging of the time-delay capacitor from the +15-VDC supply. When the delay interval is complete, a positive voltage appears at the base of transistor Q12 and the driver combination Q12, Q14 conducts, thereby energizing relay K5. If any of the "AND" No. 4 inputs are removed during the time delay No. 1 interval, the timer is immediately reset.

The stellar sensor start signal is produced by activation of "AND" No. 6 and time delay No. 3. "AND" No. 6 and time delay No. 3 operate in identical fashion to "AND" No. 4 and time delay No. 1 (previously described) to activate relay driver combination Q18, Q19 to energize relay K1. This relay provides a contact which completes a circuit that can be used for stellar sensor startup.

Both relays K5 and K1 employ one of their own contacts to permit energization of their coils through driver combination Q16 and Q15. This driver maintains the relays energized continuously until a change in state of flip-flop No. 4 cuts off Q16. Thus subsequent removal of "AND" No. 4 (or "AND" No. 6) inputs 2 and 3 does not de-energize K1 or K5.

The other contact of K5 removes an inhibiting ground from "AND" No. 5P and "AND" No. 5Y (input 1 in each case) and provides a ground to enable the relay drivers Q1 through Q8.

Energization of K5 removes 28 VDC from P15-35 signifying closure of the SACS torquing loops.

The gyro torquing control relays are operated by the Darlington compound drivers (transistors Q1 through Q8). The pitch full trigger provides a positive voltage at the base of either Q1 or Q2, depending on the sign of the summed inputs to the DC amplifier, if the amplifier output exceeds the trigger level. A positive voltage applied to the base of Q1 results in turning Q1 and Q5 hard ON, thereby completing the ground circuit for the K2 coil and permitting the relay to actuate. Torquing of the pitch gyro occurs while K2 is actuated. The direction of precession as such as to reduce the summed inputs to the amplifier to a low value. Similar operation of K3 produces gyro precession in the opposite direction. When the DC amplifier output is below the trigger level, both K2 and K3 are de-energized. The yaw drivers and relays operate in an identical fashion. Energization of either torque control relay K2 or K3 removes 26 V $\underline{/0^{\circ}}$ from P15-37. Similarly, energization of either K7 or K8 removes 26 V $\underline{/0^{\circ}}$ from P15-33.

Valve switchover operation is identical for pitch and yaw. As noted, energization of K5 removes an inhibiting ground from input 1 of "AND" No. 5P and "AND" No. 5Y. At any time thereafter, when input 2 is present (gyro error below half-trigger level), time delay No. 2P or No. 2Y is activated. The half-triggers will normally produce no output for several seconds after activation of gyro torquing (K5 energization). This is because the gyros are being torqued in a direction which will result in target acquisition and gyro errors may exceed the half-trigger levels during this time. As acquisition nears completion, the half-triggers apply positive voltages at input 2 of "AND" No. 5P and/or "AND" No. 5Y. With both inputs present, the capacitor in time delay No. 2 is permitted to charge from the 15-VDC supply. If this condition persists for the time-delay interval, the relay drivers (Q9-Q11 in pitch; Q10-Q13 in yaw) conduct and provide a grounding circuit for the valve switchover relays (K4 in pitch; K6 in yaw) and these relays are energized.

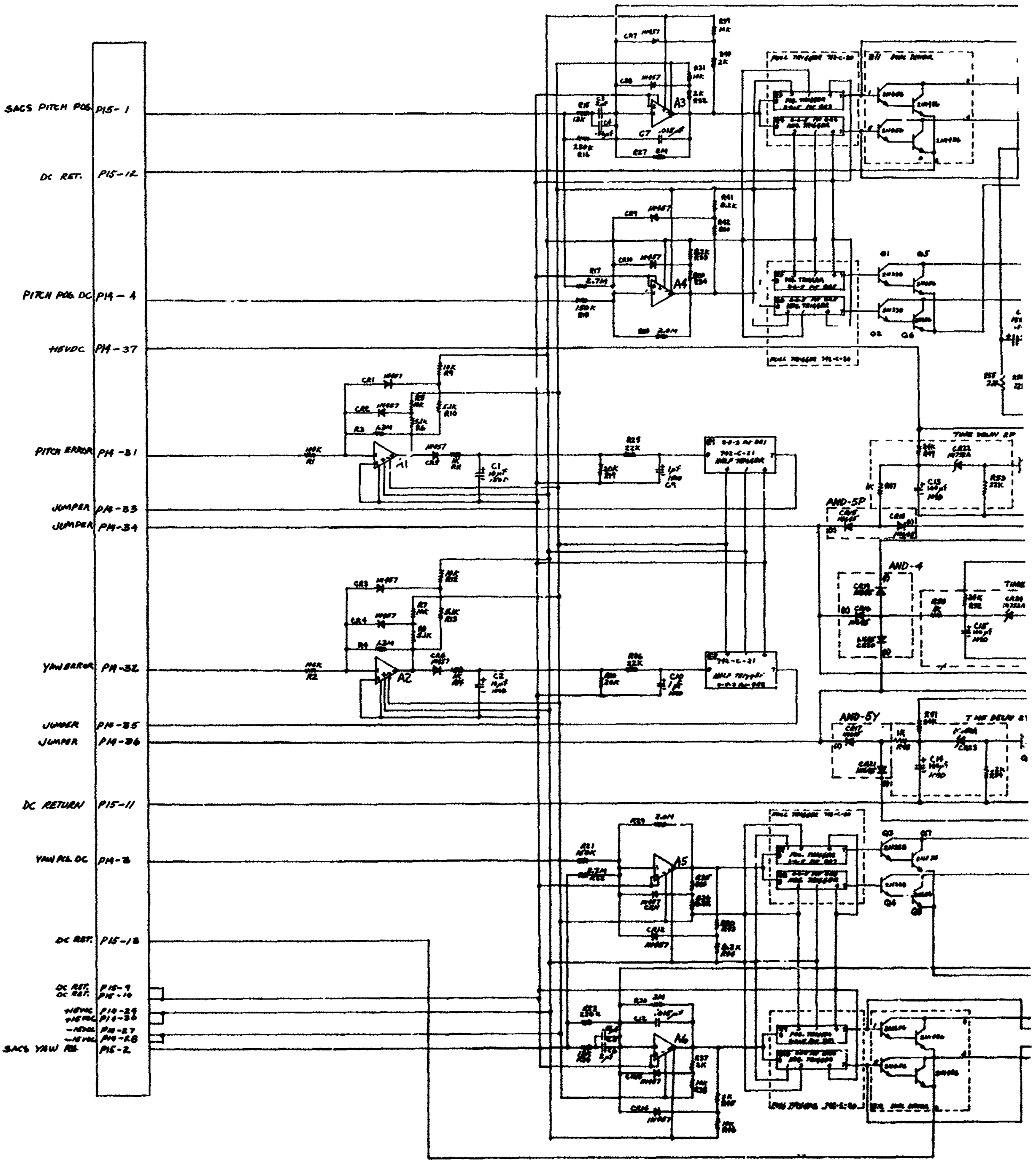
These time delay circuits also have fast reset capability. The pitch and yaw time delay and driver circuits are independent so that the change-over sequence proceeds as rapidly as possible in each channel.

Actuation of relay K4 applies 28 VDC to the SACS pitch solenoid valve coils and removes 28 VDC from the IACS pitch solenoid valve coils. Relay K6 provides the same function for the yaw solenoid valve coils. Energization of K4 applies 28 VDC at P15-36 for monitoring purposes. Energization of K6 applies 28 VDC at P15-34.

When relays K4 and K6 are energized, turn-on of the SACS solenoid valves is controlled by Darlington drivers. The full triggers preceding the drivers produce turn-on of the appropriate driver whenever the amplified solar sensor output signal exceeds the trigger level. The resultant solenoid valve actuation produces a reaction force on the vehicle in such a direction as to reduce the solar sensor output. Attitude control by the SACS continues as long as a programmer hold condition persists.

The SACS is deactivated automatically by starting to torque the gyros to the next target. If gyro torquing is programmed to occur at the end of the hold period, a ground appears at P14-8 and changes the state of flip-flop No. 4. This turns Q17 hard ON. With Q17 conducting, the Q16-Q15 driver is cut off and the inhibiting ground is restored at input 1 of "AND" No. 4 and "AND" No. 6. K1 and K5 de-energize. When K5 de-energizes the torque control relay drivers are disabled by opening of their grounding circuit and the inhibiting ground is restored at input 1 of "AND" No. 5P and "AND" No. 5Y. The valve switchover drivers are cut off and relays K4 and K6 de-energize, thereby removing 28 VDC from the SACS valves and reapplying it to the IACS valves.

Caging the gyros from the GSE is accomplished by relays K9 and K10. Relays K9 and K10 are energized when gyro caging is initiated from the GSE. Energization of K9 connects the pitch torquer windings (P15-21) and (P15-22) to the GSE (P14-17) and (P14-18). The SACS torque control relays K2 and K3 are separated from the torquer windings. Relay K10 performs similarly in yaw.



SACS PITCH POS
P15-1
DC RET.
P15-12
PITCH POS. DC
P14-4
+15VDC
P14-37
PITCH ERROR
P14-31
JUMPER
P14-33
JUMPER
P14-34
YAW ERROR
P14-32
JUMPER
P14-35
JUMPER
P14-36
DC RETURN
P15-11
YAW POS. DC
P14-3
DC RET.
P15-13
SACS YAW POS.
P15-2
A1
A2
A3
A4
A5
A6
AND-5P
AND-4
AND-5Y

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1

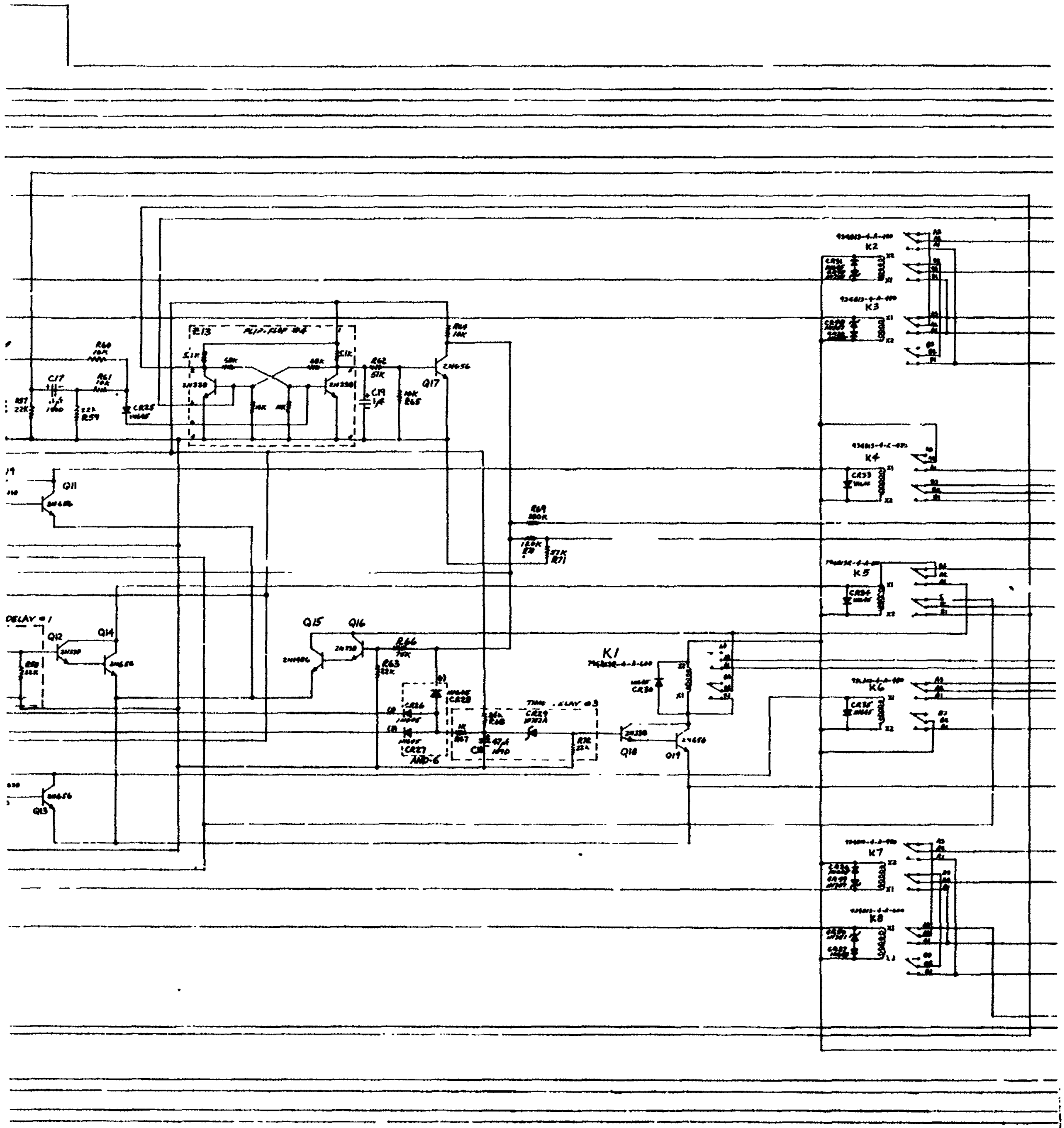
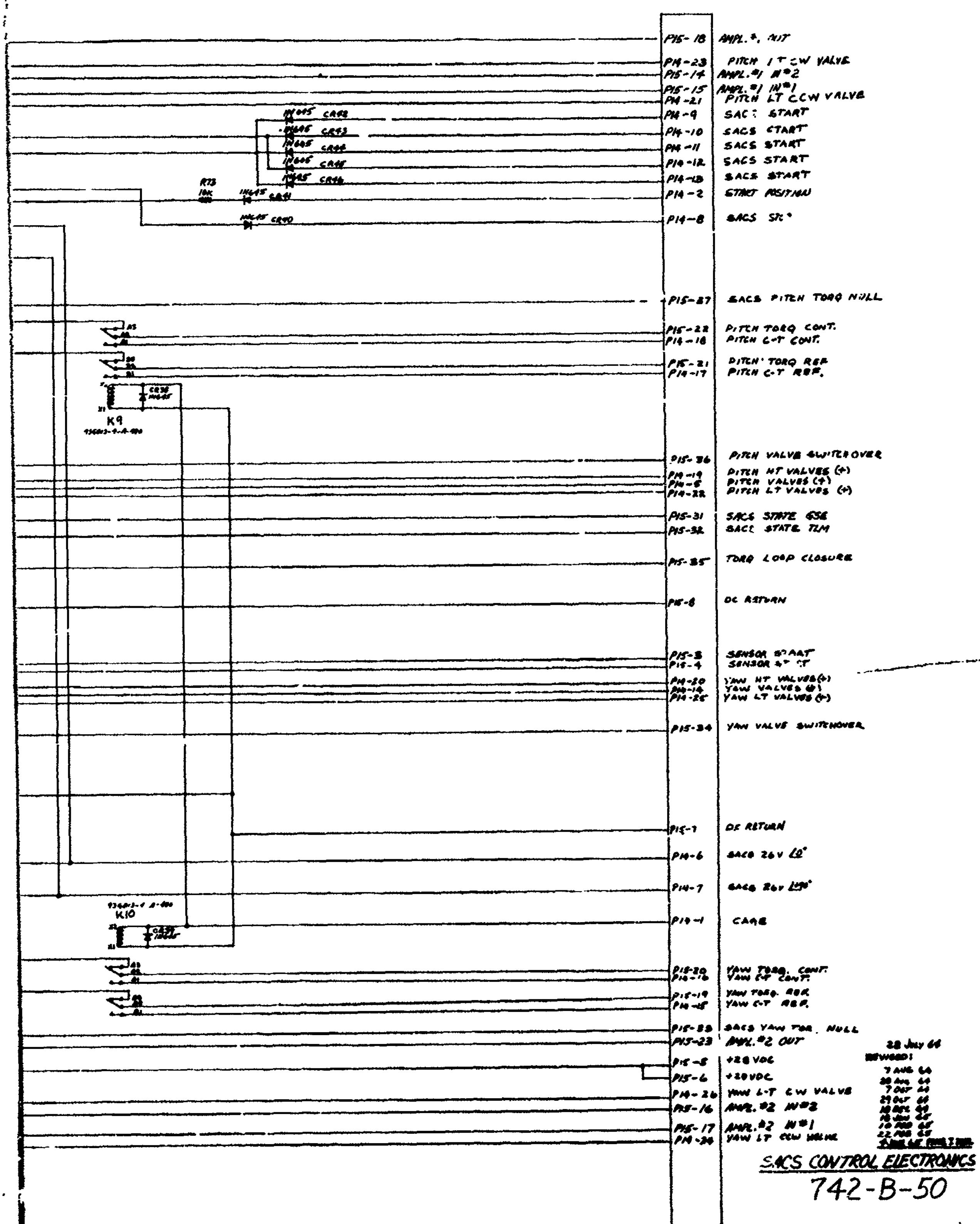


Figure I-7. Schematic, SACS Control Electronics Subassembly
(Sketch 742-B-50)



SACS CONTROL ELECTRONICS

742-B-50

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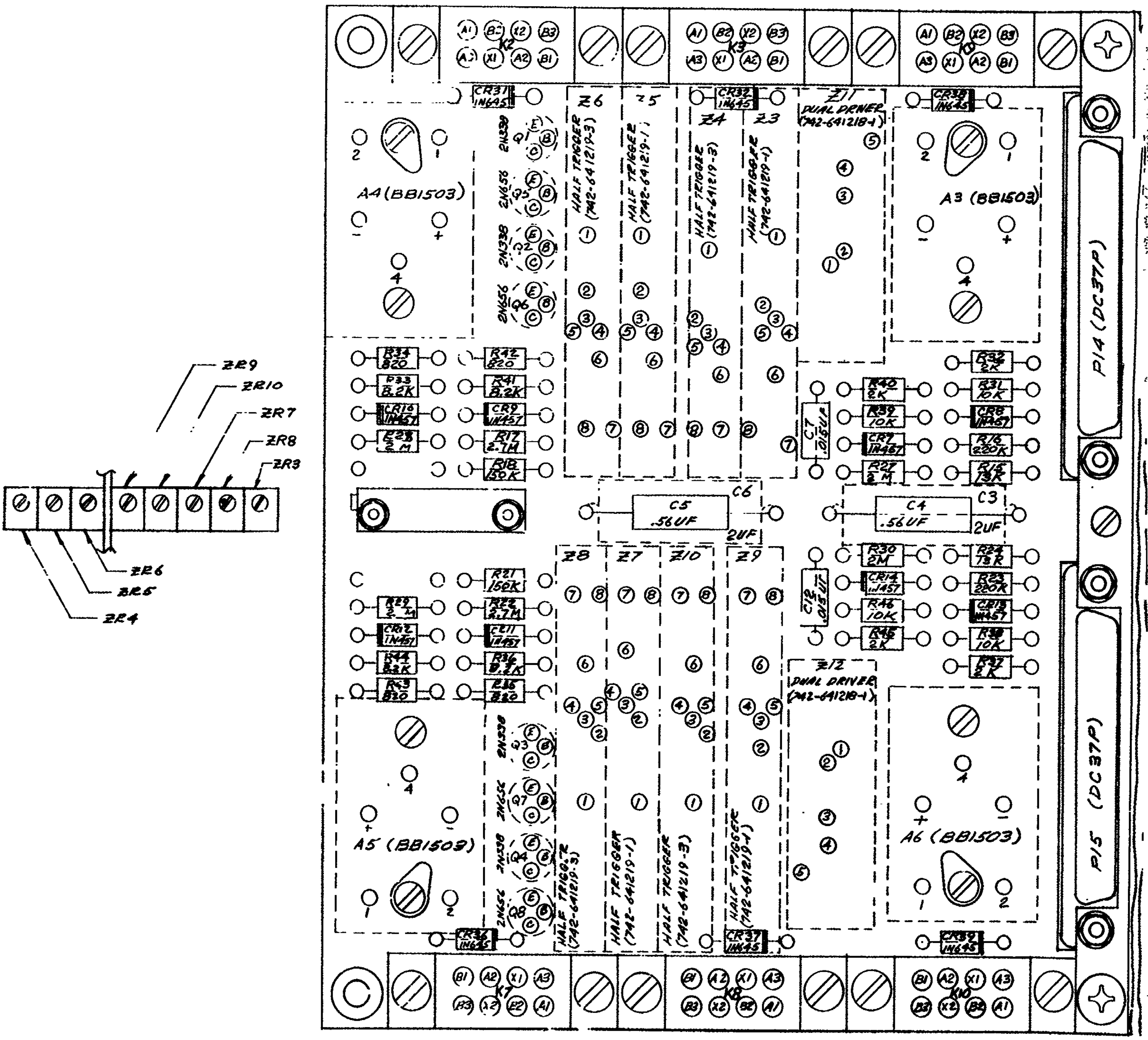
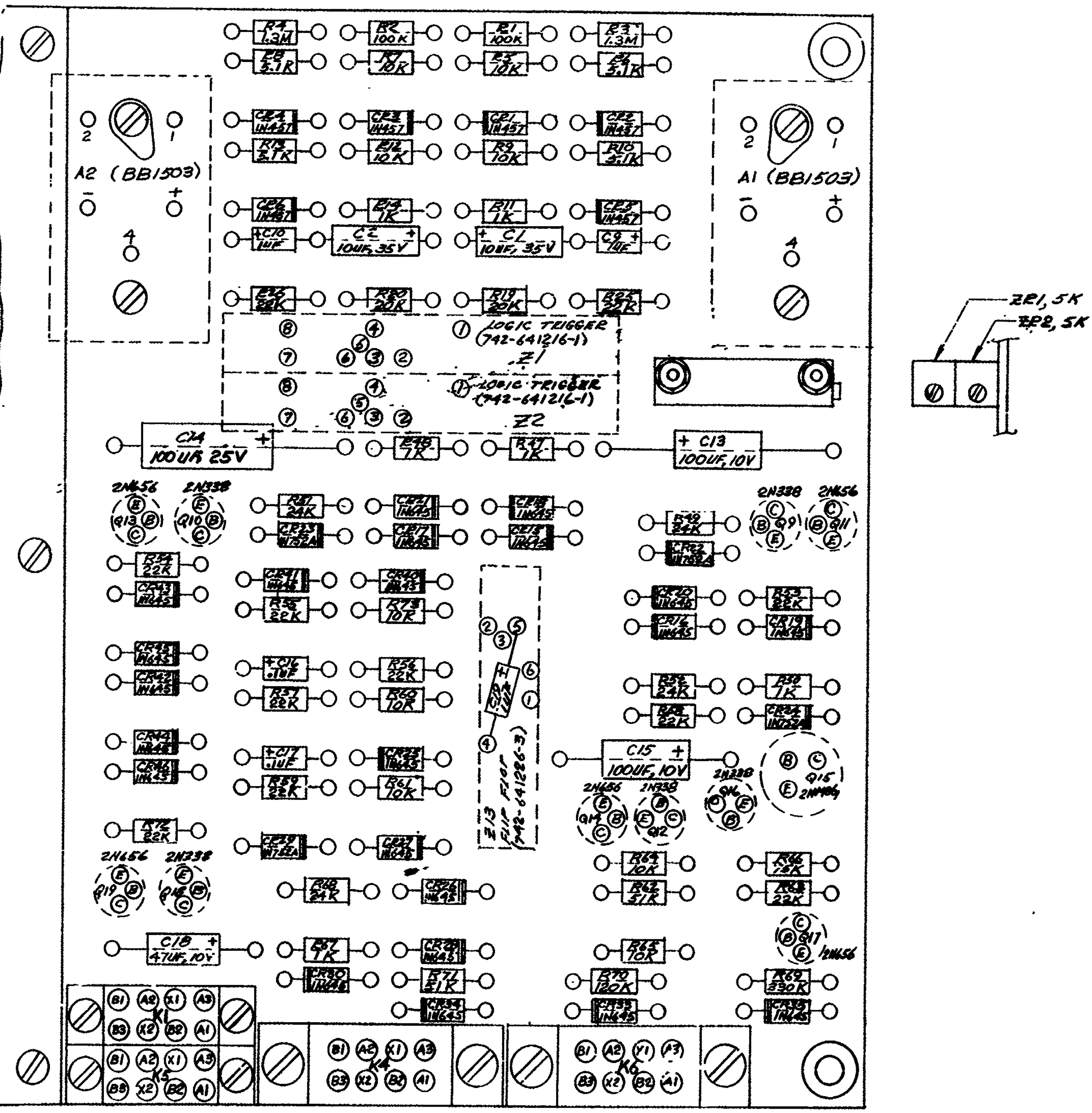


Figure I-8. Layout, SACS Control El
(Sketch 742-641208



ectronics Subassembly
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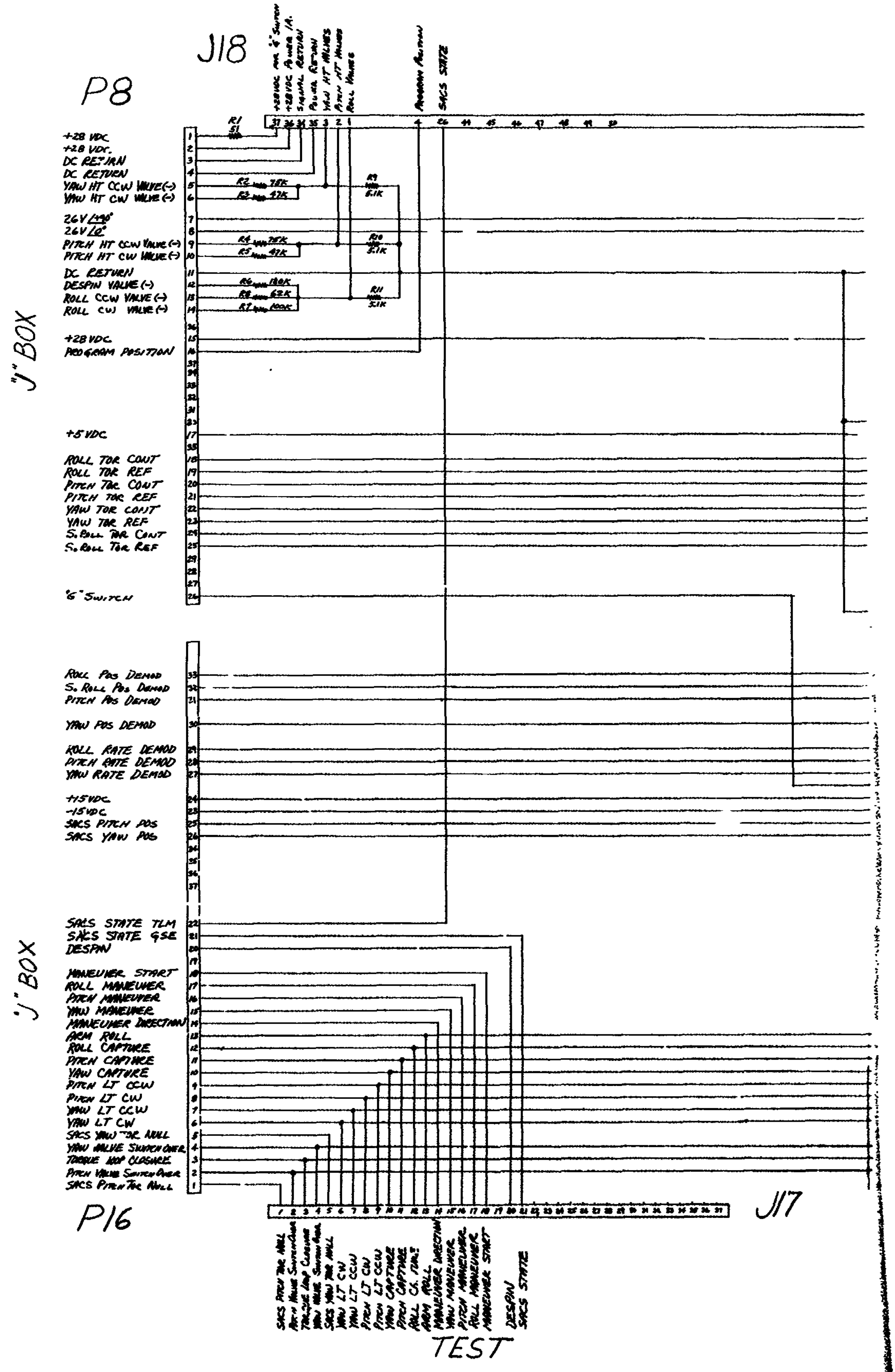
F. TELEMETRY SIGNAL CONDITIONING

The telemetry signal conditioning subassembly contains the circuitry required to monitor and condition all FACS signals prior to being delivered to the telemetry system. All signals are conditioned 0 to +5 VDC. A schematic diagram of the telemetry signal conditioning subassembly is shown in Figure I-9 and the component layout in Figure I-10.

All FACS telemetry calibration data appears in Appendix VI.

TELEM



J18
P8
+28 VDC
+28 VDC
DC RETURN
DC RETURN
YAW HT CCW VALVE (-)
YAW HT CW VALVE (-)
26V /90°
26V /0°
PITCH HT CCW VALVE (-)
PITCH HT CW VALVE (-)
DC RETURN
DESPIN VALVE (-)
ROLL CCW VALVE (-)
ROLL CW VALVE (-)
+28 VDC
PROGRAM POSITION
+5 VDC
ROLL TOR CONT
ROLL TOR REF
PITCH TOR CONT
PITCH TOR REF
YAW TOR CONT
YAW TOR REF
S. ROLL TOR CONT
S. ROLL TOR REF
"G" SWITCH
"J" BOX
ROLL POS DEMOD
S. ROLL POS DEMOD
PITCH POS DEMOD
YAW POS DEMOD
ROLL RATE DEMOD
PITCH RATE DEMOD
YAW RATE DEMOD
+15 VDC
-15 VDC
SACS PITCH POS
SACS YAW POS
SACS STATE TLM
SACS STATE GSE
DESPIN
MANEUVER START
ROLL MANEUVER
PITCH MANEUVER
YAW MANEUVER
MANEUVER DIRECTION
ARM ROLL
ROLL CAPTURE
PITCH CAPTURE
YAW CAPTURE
PITCH LT CCW
PITCH LT CW
YAW LT CCW
YAW LT CW
SACS YAW TOR NULL
YAW VALVE SWITCH OVER
TORQUE LOOP CLOSURE
PITCH VALVE SWITCH OVER
SACS PITCH TOR NULL
"J" BOX
P16
J17
PROGRAM POSITION
SACS STATE
R1 51
R2 75K
R3 47K
R4 75K
R5 47K
R6 180K
R8 68K
R7 100K
R9 5.1K
R10 5.1K
R11 5.1K
ROLL CA. TORQ
TEST

I-35 ①

METRY

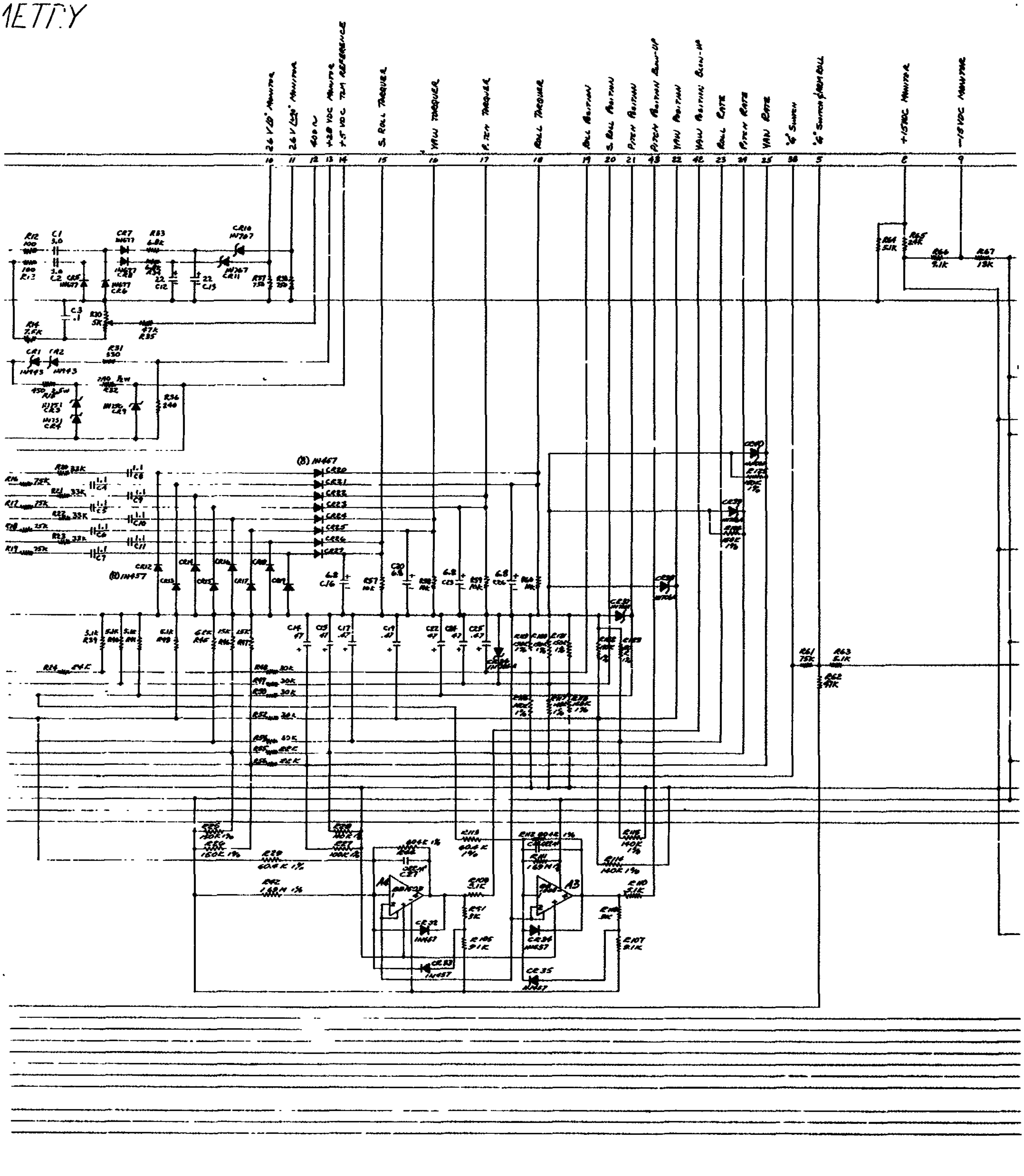
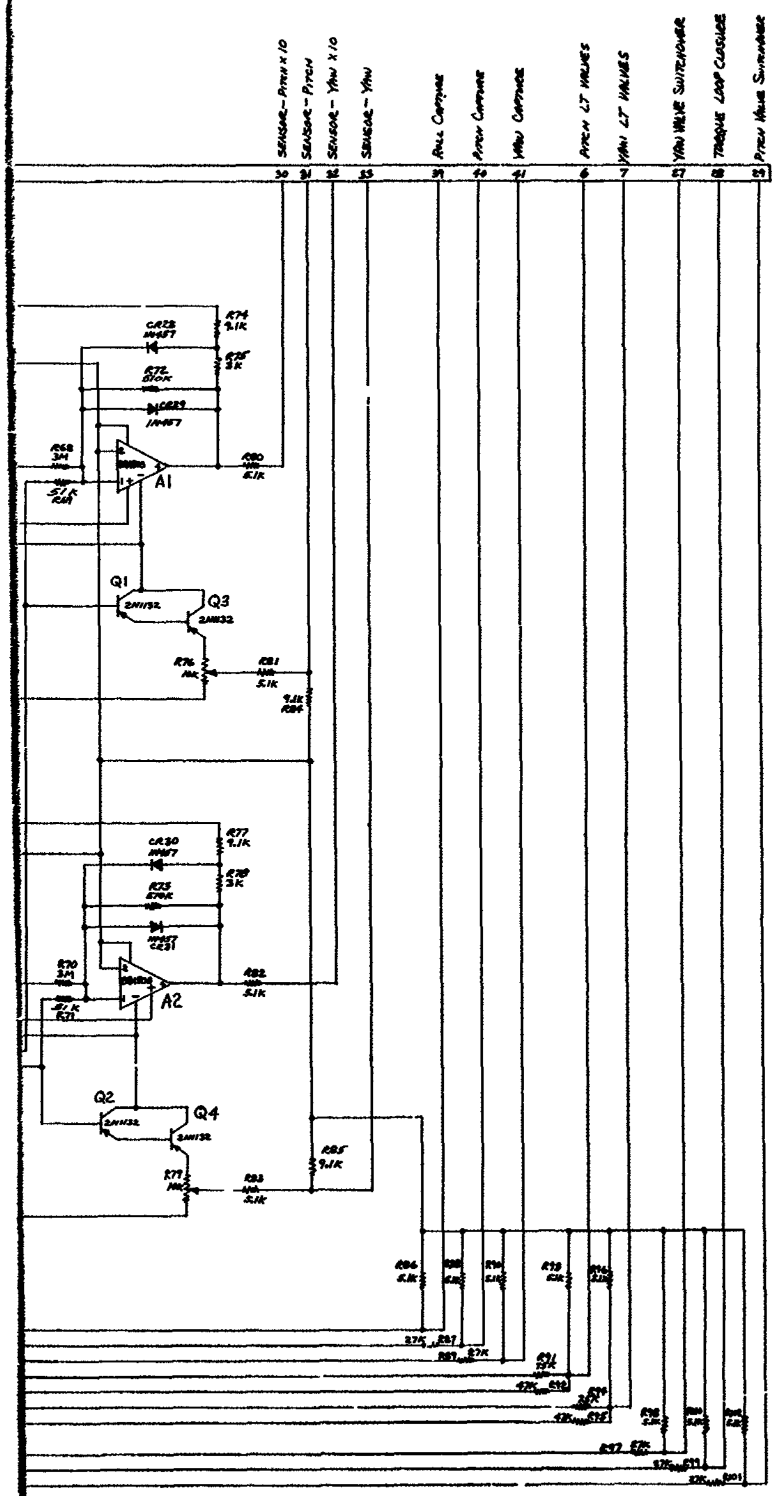


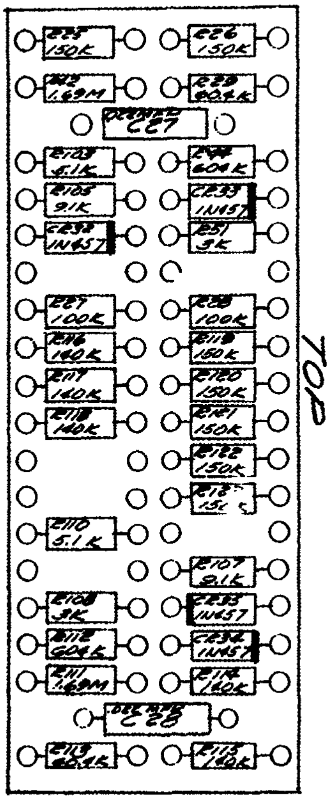
Figure I-9. Schematic, Telemetry Signal Conditioning Subassembly
(Sketch 742-B-90)



742-B-90

LM CONDITIONING

20 OCT 64
REVISED: 29 OCT 64
20 NOV 64
8 DEC 64
2 FEB 65
18 FEB 65
4 JUNE 65 PHASE I FINAL



TB1
NOT TO SCALE

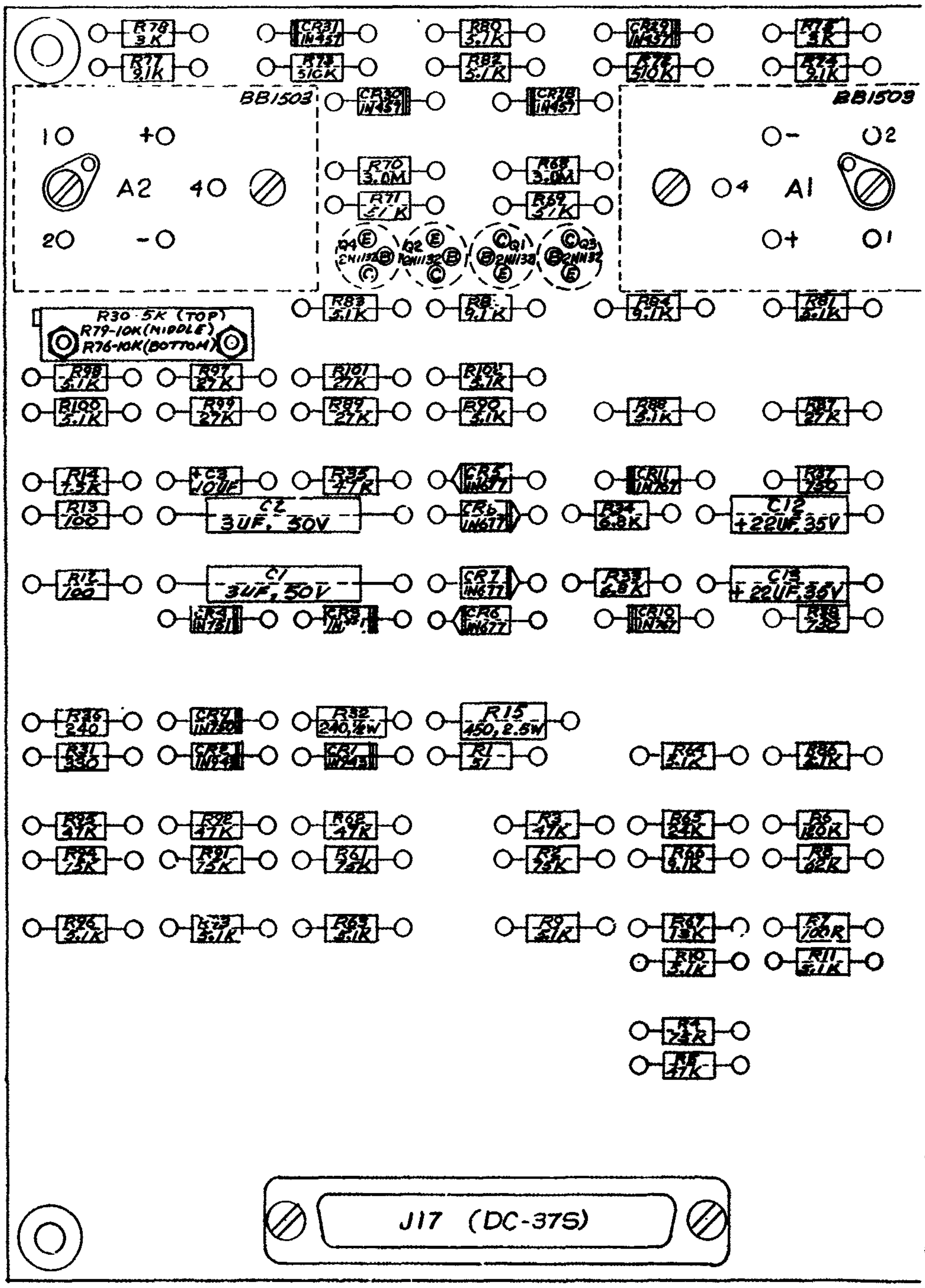
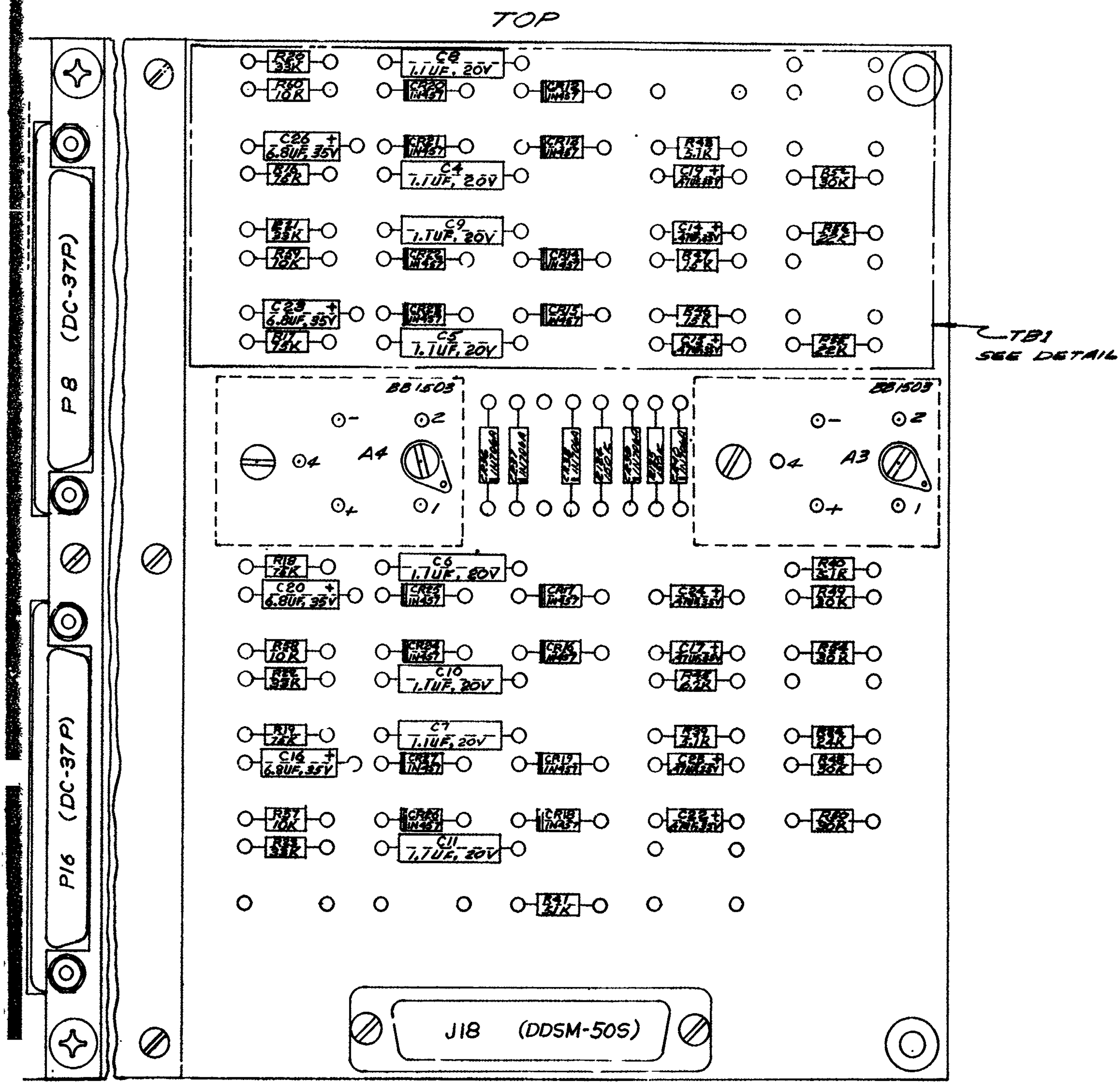


Figure I-10. Layout, Telemetry
(Sketch 74

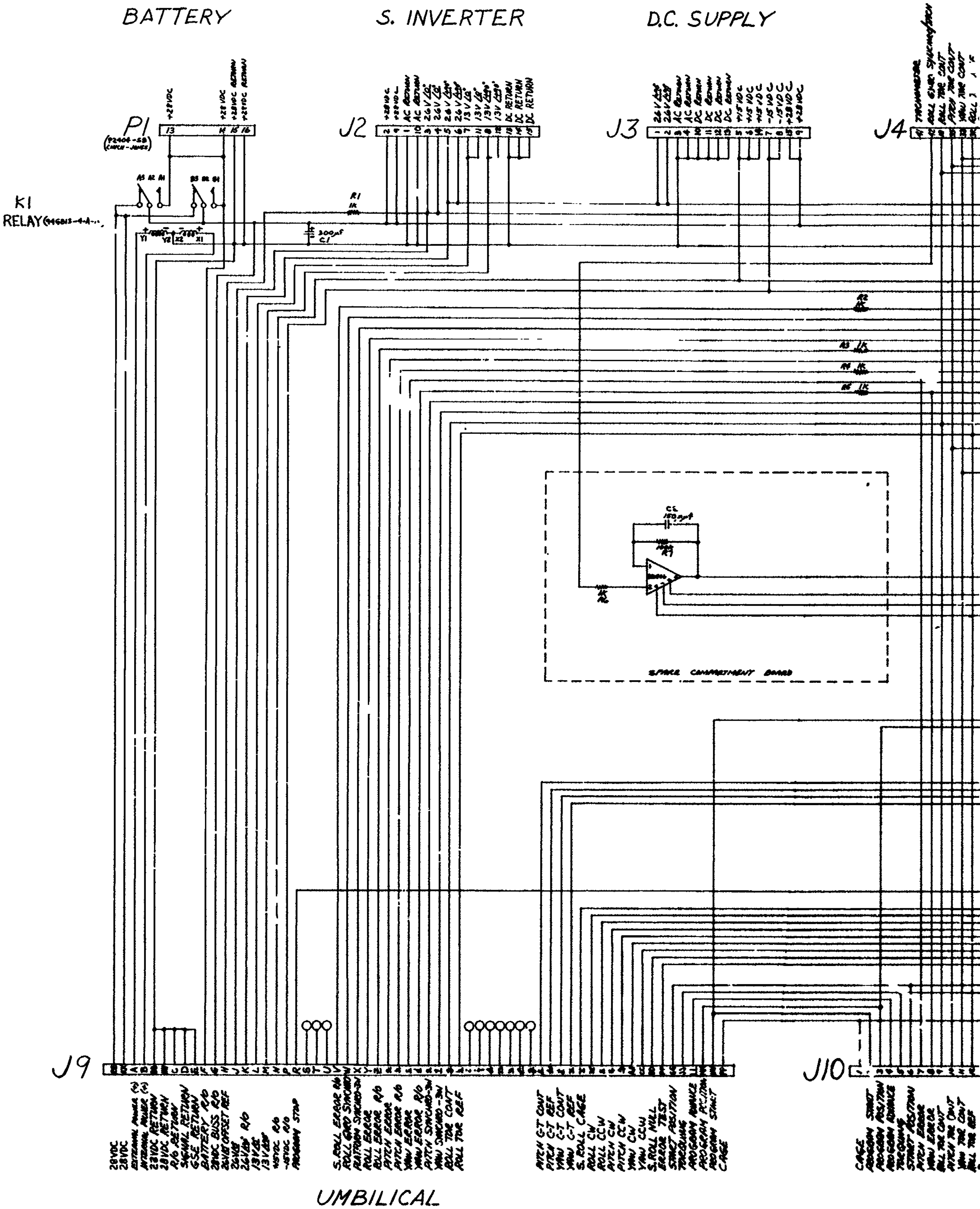


Signal Conditioning Subassembly
2-641117)

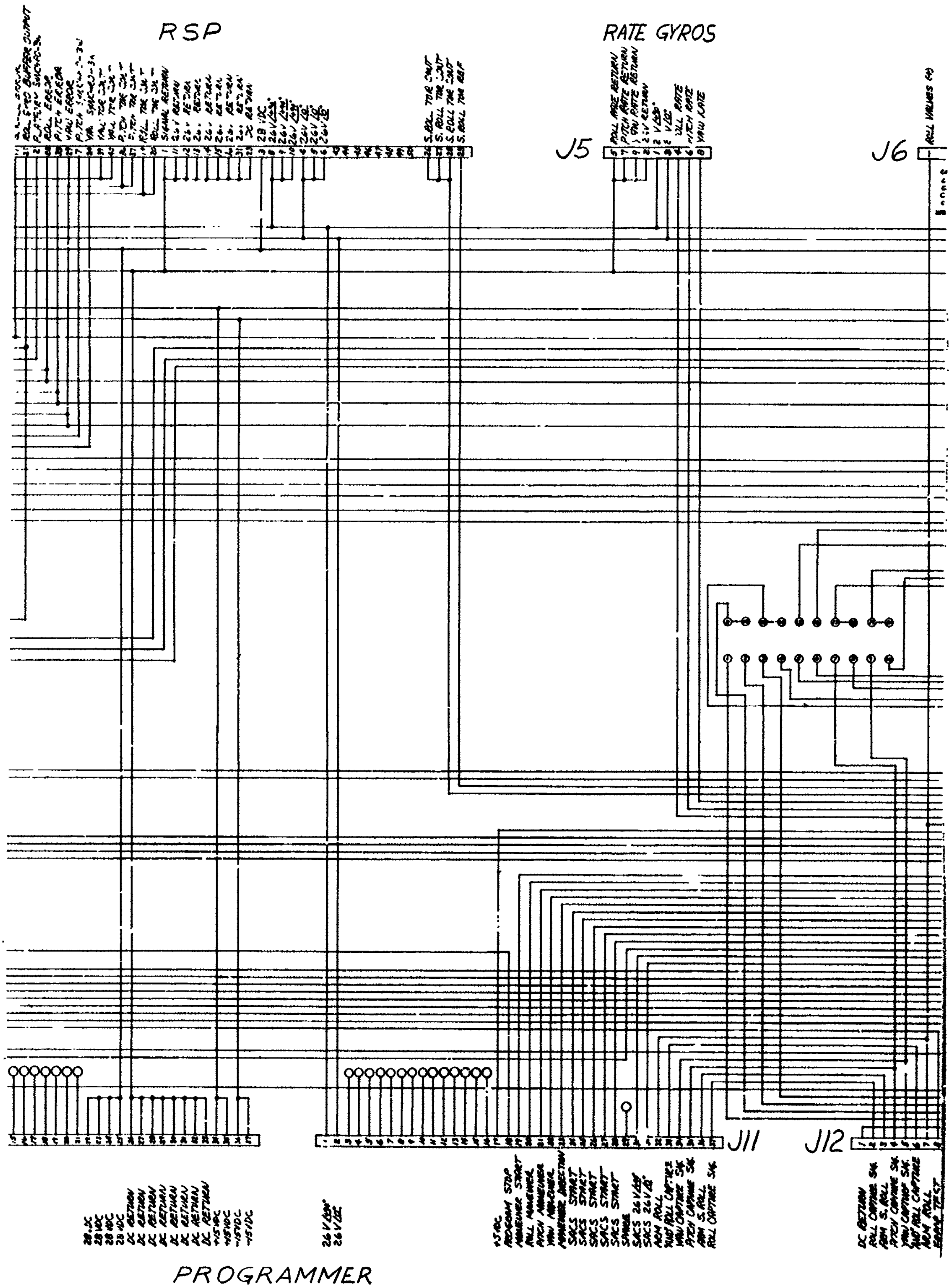
2

G. JUNCTION BOX

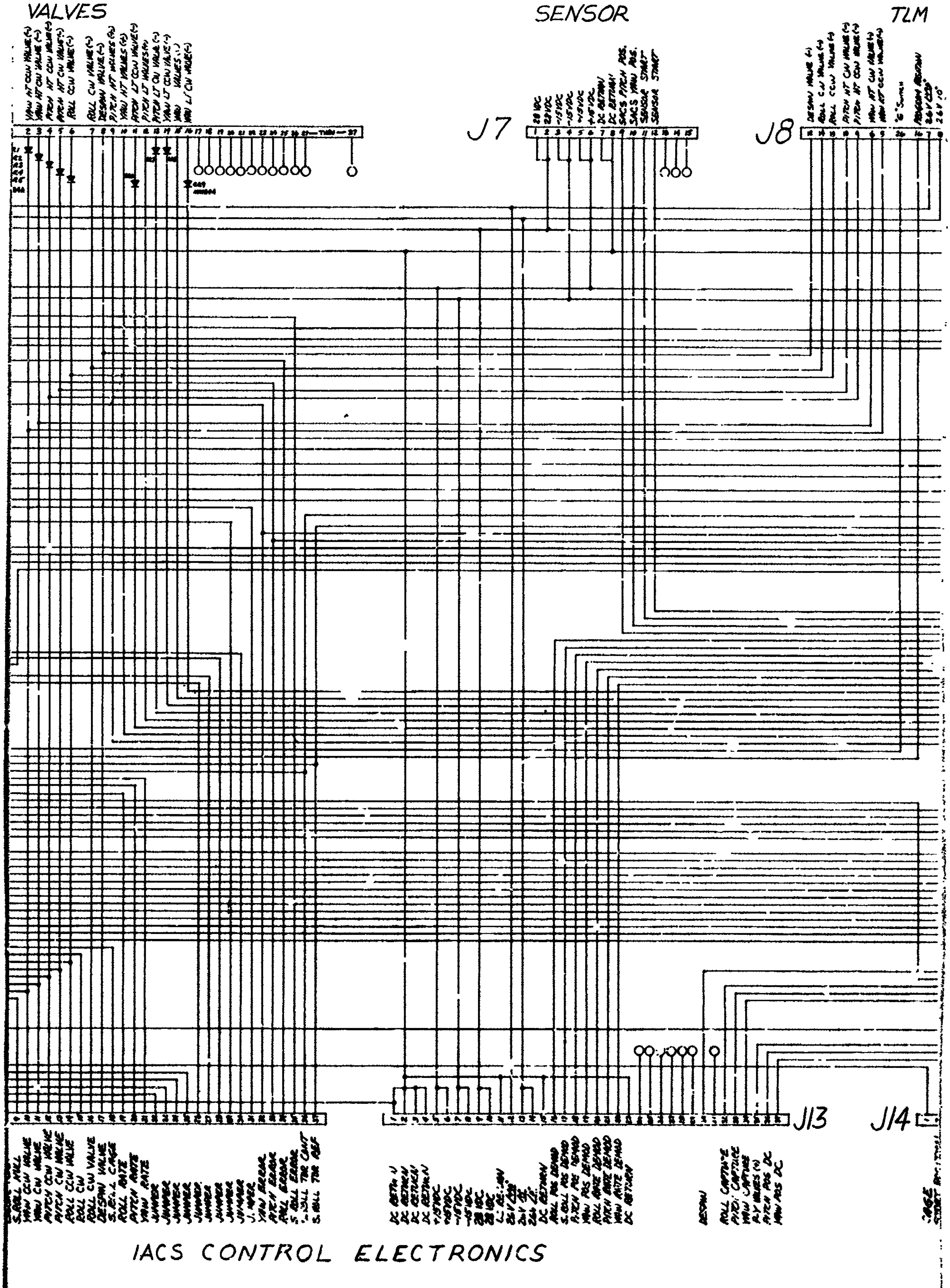
The junction ("J") box is the FACS power distribution and subassembly interconnection center. The system harnessing is an integral part of the "J" box. A latching relay for system switchover from the GSE power supply to the vehicle FACS battery supply is also incorporated into the "J" box. A schematic diagram of the "J" box is shown in Figure I-11 and a physical layout in Figure I-12.



BATTERY
S. INVERTER
D.C. SUPPLY
P1
J2
J3
J4
K1
RELAY
SPARE COMPARTMENT BOARD
J9
J10
UMBILICAL


RSP
RATE GYROS
J5
J6
J11
J12
S. ROLL TDR OUT
S. ROLL TDR REF
ROLL RATE RETURN
PITCH RATE RETURN
YAW RATE RETURN
26V RETURN
PITCH RATE
YAW RATE
ROLL VALVES
PROGRAM STOP
MANEUVER START
ROLL MANEUVER
PITCH MANEUVER
YAW MANEUVER
MANEUVER DIRECTION
SACS START
SPARE
ARM ROLL
NAV ROLL CAPTURE
YAW CAPTURE SW.
PITCH CAPTURE SW.
ROLL CAPTURE SW.
DC RETURN
ARM S. ROLL
ERROR TEST
28 VDC
DC RETURN
PROGRAMMER

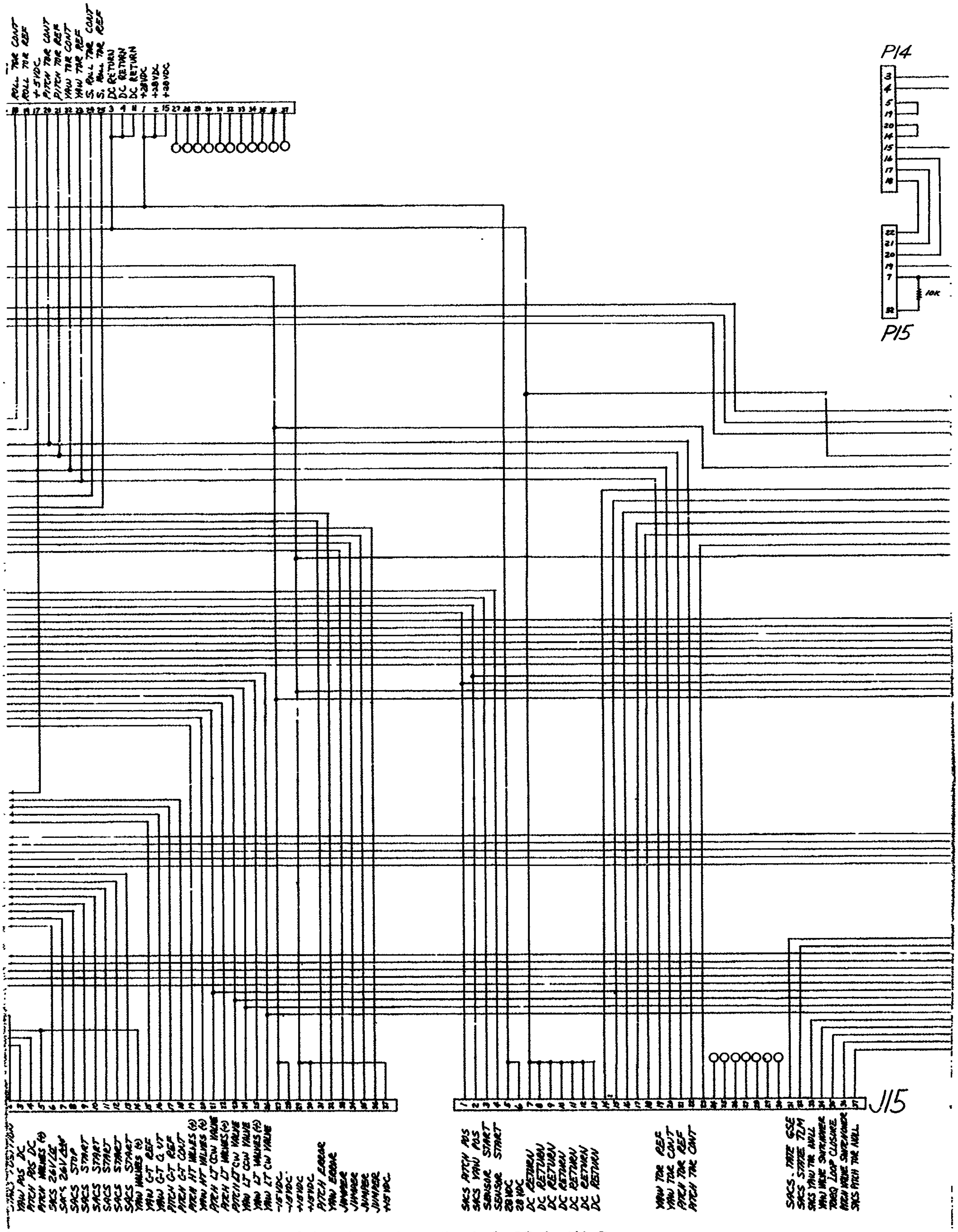
Fi



gure I-11. Schematic, "J" Box Subassembly (Sketch 742-B-60)

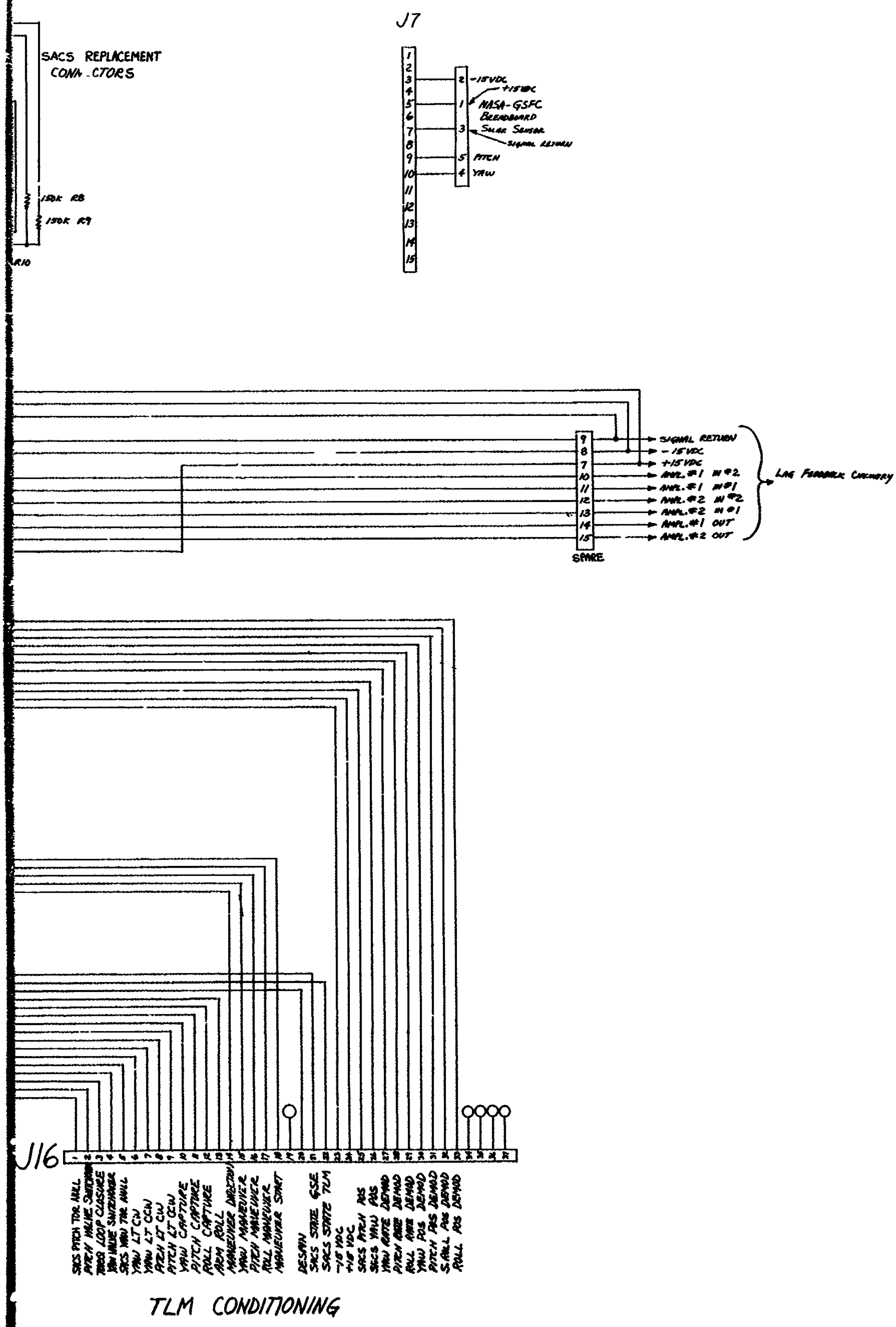
I-38 (3)

CONDITIONING



SACS CONTROL ELECTRONICS

T-38(4)



J7
SACS REPLACEMENT CONN. CTORS
150K R8
150K R9
R10
-15VDC
+15VDC
NASA-GSFC BREADBOARD SOLAR SENSOR
SIGNAL RETURN
PITCH
YAW
SIGNAL RETURN
-15VDC
+15VDC
AMPL.#1 IN #2
AMPL.#1 IN #1
AMPL.#2 IN #2
AMPL.#2 IN #1
AMPL.#1 OUT
AMPL.#2 OUT
LAG FEEDBACK CIRCUITRY
SPARE
J16
SACS PITCH TOR. NULL
PITCH VALVE SWITCHING
TORQ. LOOP CLOSURE
YAW VALVE SWITCHING
SACS YAW TOR. NULL
YAW LT CW
YAW LT CCW
PITCH LT CW
PITCH LT CCW
YAW CAPTURE
PITCH CAPTURE
ROLL CAPTURE
ARM ROLL
MANEUVER DIRECTION
YAW MANEUVER
PITCH MANEUVER
ROLL MANEUVER
MANEUVER START
DESPIN
SACS STATE GSE
SACS STATE TLM
-15 VDC
+15 VDC
SACS PITCH POS
SACS YAW POS
YAW RATE DEMOD
PITCH RATE DEMOD
ROLL RATE DEMOD
YAW POS DEMOD
PITCH POS DEMOD
S.ROLL POS DEMOD
ROLL POS DEMOD
TLM CONDITIONING

5

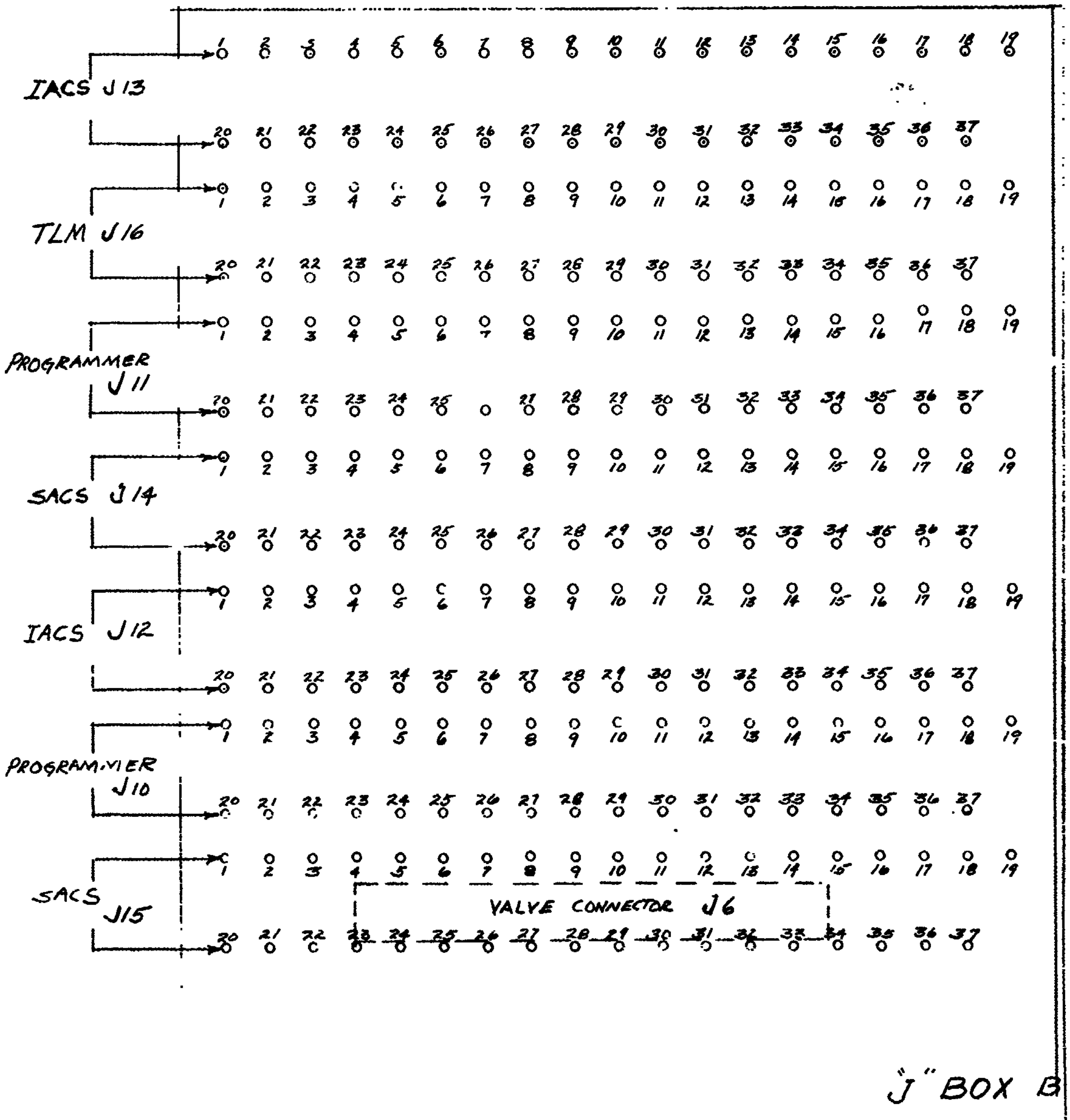
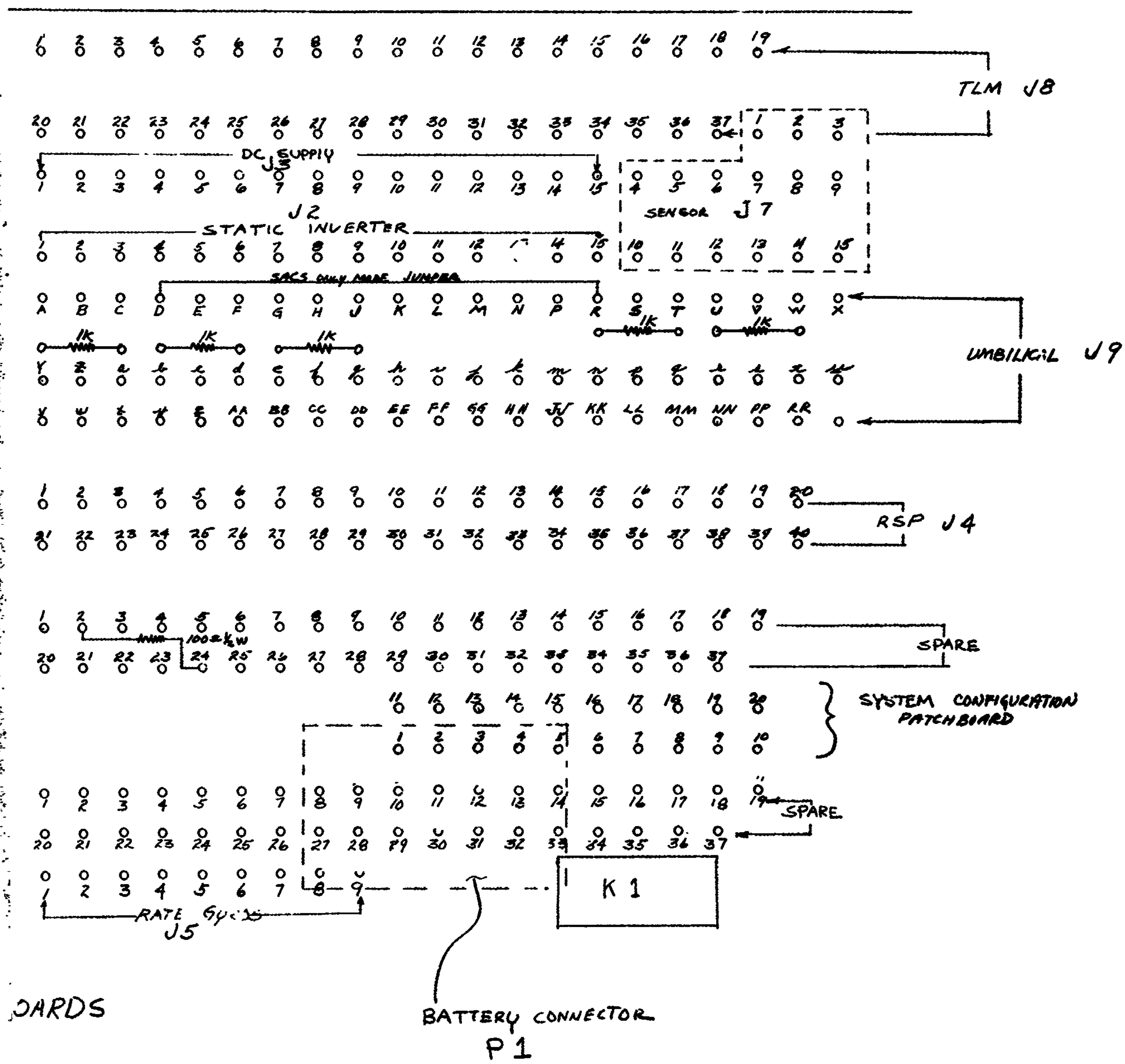


Figure I-12. Layout, "



ОARDS

J" Box Subassembly

(21)

H. ROLL STABILIZED PLATFORM

The roll stabilized platform establishes the FACS three-axis inertial reference. In the attitude control of spin stabilized rocket vehicles, significant improvement in gyro performance can be achieved by isolating the gyros from the spin environment. The Space-General Corporation roll stabilized platform (RSP) accomplishes this isolation.

The platform gimbal servo is composed of the roll-pitch gyro outer gimbal synchro, a resistive summing network, a servo amplifier, a servo motor-tachometer, a platform driven synchro, and the drive gearing. All components are mounted internally.

The servo is null seeking and acts to reduce the angle between the roll-pitch gyro outer gimbal and the gyro case (or platform) to zero. Damping is provided by resistively summing the tachometer signal with the gyro signal prior to amplification. The two-phase servo motor mounted on the moving platform drives the system to null through suitable gearing.

A synchro mounted between the platform and the vehicle provides a measure of the angle between the platform and vehicle. This synchro output is summed with the roll gyro synchro output to produce a vehicle control system signal unaffected by platform dynamics.

A schematic of the RSP is shown in Figure I-13.

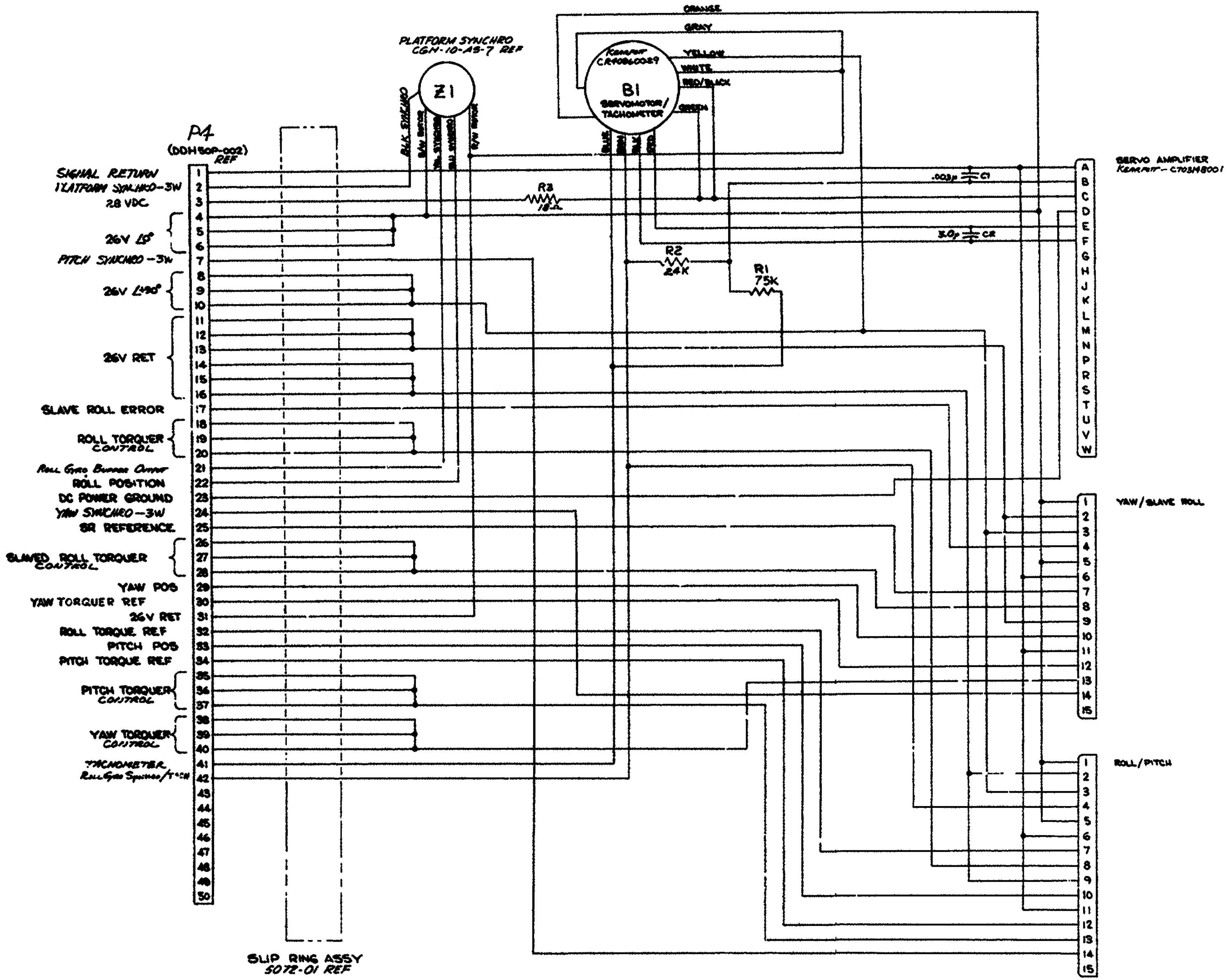


Figure I-13. Schematic, Roll Stabilized Platform Subassembly
(Sketch 742-B-80)

I. RATE GYROS

The rate gyro subassembly contains three mutually orthogonal rate gyros. Rate gyros are used in the FACS for IACS rate feedback damping in the roll, pitch and yaw control channels. A schematic diagram of the rate gyro subassembly is shown in Figure I-14.

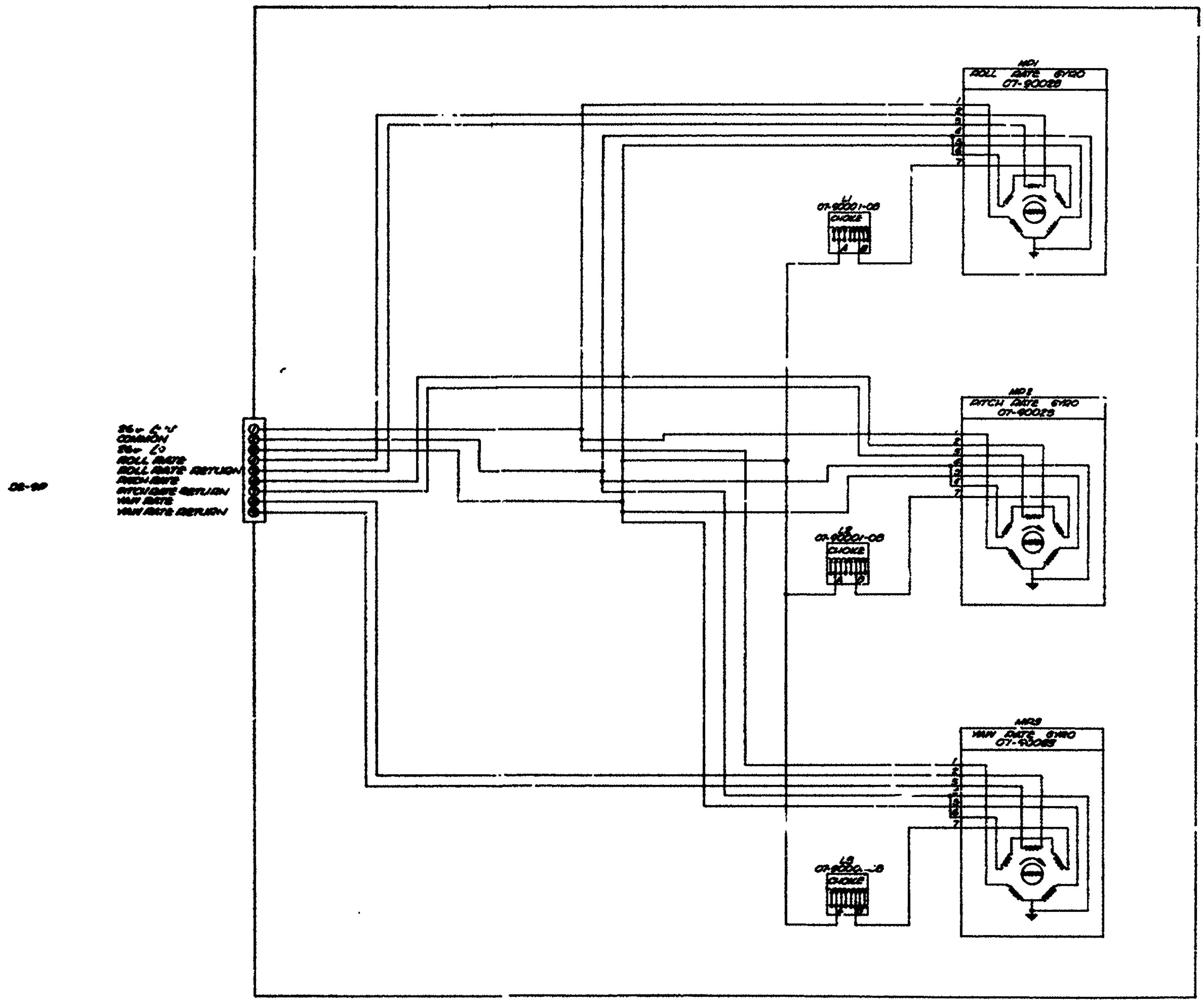


Figure I-14. Schematic, Rate Gyro Subassembly (Sketch 742-B-70)

J. FACS BREADBOARD GSE SYSTEM DESCRIPTION

GENERAL

The FACS GSE system consists of equipment for support of FACS test and checkout. The GSE is connected to the FACS through an umbilical cable and a test cable (see Figure I-15). The latter cable is used for monitoring functions during laboratory checks only. Refer to Figures I-16, I-17 and I-18 for the schematic diagrams of the FACS GSE system.

The functions of the GSE system are to:

a. supply external 28 VDC to the FACS

b. provide operating control of the FACS

c. provide both normal and offset caging control of the FACS

d. provide visual indication related to FACS operation

e. provide test points for monitoring FACS voltages

GSE POWER SUPPLY CIRCUITRY

The main power supply is required to supply +28 VDC to the FACS flight system as an external power source. This supply is utilized primarily for supplying power to the FACS; +28-VDC power for GSE circuits is provided by a separate GSE +28-VDC power supply. The main power supply has the following minimum characteristics:

a. Current capacity - 25 amps

b. Output voltage - 0 VDC to 36 VDC

c. Line regulation - 0.05% max

d. Load regulation - 0.05% max

e. Ripple - 1 mv (rms) max

The output voltage is adjustable by means of a voltage control potentiometer.

The auxiliary power supply provides +28 VDC operating power to the GSE control circuits and to the GSE indicator lamp circuits. This power source is isolated from the main power supply. The electrical specifications for the auxiliary power supply are as follows:

a. Current capacity - 2 amps

b. Output voltage - +28 VDC

c. Line regulation - 0.05% max

d. Load regulation - 0.05% max

e. Ripple - 1 mv (rms) max

The ±15-VDC supply provides operating power to the GSE caging and control circuits. The auxiliary 28-VDC supply supplies power to the +15-VDC regulator circuit. The -15-VDC supply receives its power from the 60-cycle line. The series regulators utilized here are identical to that in the FACS flight system.

GSE CONTROL CIRCUITRY

THE FACS POWER CONTROL SELECTOR consists of a double pole three position switch. Position 1 is the off position. Position 2 applies +28 VDC to one coil of the FACS power switchover latching relay, which in turn applies the external +28-VDC power to the FACS. Position 3 transfers the +28 VDC to the other coil of the FACS latching relay, which switches the FACS to internal power. The ammeter on the console is used for indicating FACS externally supplied DC current only. The GSE operating power is applied to the GSE circuitry by a relay which is energized when the GSE power control selector is on either the external or internal power position.

THE PROGRAM START SWITCH simulates the actuation of the vehicle "G" reduction switch which initiates operation of the FACS coast time delay circuit by energizing a self-locking relay in the FACS programmer. This switch applies +28 VDC to this relay.

THE PROGRAM ADVANCE SWITCH applies ground to the negative terminal of the programmer ledex coil which steps the ledex to the position desired by the GSE operator.

THE PROGRAM STOP SWITCH applies a ground to the "AND" No. 3 circuit of the programmer, which inhibits any signal from firing the one-shot multivibrator that turns on the ledex driver transistors. With this switch actuated, the ledex cannot step automatically, but can be stepped manually by the Program Advance switch. A section of this switch is in series with the Maneuver Start switch (described below) so that a maneuver cannot be manually started unless the program has been manually stopped at the GSE.

THE MANEUVER START SWITCH applies +28 VDC to flip-flop No. 3 of the programmer and sets it to its required state for starting a maneuver. This switch can start a maneuver only if the Program Stop switch is in the program stop position.

THE ERROR TEST SWITCH supplies +28 VDC to K6 and K8 of the IACS control electronics. Energizing these relays closes contacts which connect the valve driver emitters to ground. In the GSE, this switch supplies +28 VDC to one side of all the valve indicators.

THE CAGE SWITCH is a momentary-type push button switch that energizes a GSE caging relay. The contacts on this relay perform the following functions when the relay is energized.

a. Allows a +15 VDC no-torquing voltage from the FACS programmer to turn on a driver that supplies ground to the output drivers in the pitch, yaw and roll GSE caging control channels.

b. Supplies +28 VDC to the FACS to energize the proper relays required to cage the system. This voltage is also supplied to one side of all the GSE valve indicators.

c. Supplies a ground to the slave roll output drivers which energize relays that cage the FACS slave roll gimbal. This ground is also used to energize the cage slave roll indicator circuit in the GSE.

Offset caging level and direction is accomplished by a selector switch/potentiometer network in each caging control channel. Operation of this network is described below.

GSE PITCH CAGING CHANNEL

The function of the pitch caging channel is to accept the error signal of the pitch gyro and process it to drive the pitch gyro to its null. This caging system is capable of caging the gyro to the vehicle body axis or to a desired offset position.

The two methods of caging are herein designated as the 2-wire and 3-wire (synchro) methods. To select the desired method, a three-pole, two-position switch is used. In the 2-wire configuration, an error voltage from two stator windings of the pitch gyro synchro is applied directly to the pitch control channel. In the 3-wire method, error voltages from all three stator windings of the pitch gyro synchro are utilized by connecting the gyro stator windings to a synchro control transformer in the GSE. The resulting voltage across the GSE control transformer rotor is then applied to the control channel.

The pitch error signal sensed, either during a 2-wire or 3-wire operation, is applied to the primary of an input transformer. The center-tapped secondary is connected to a demodulator circuit whose output is filtered through a two-section, low-pass RC filter.

The filtered DC error signal from the pitch demodulator filter section is fed to a Burr Brown operational amplifier with appropriate feedback. At the input of the amplifier, a variable DC bias voltage of either plus or minus can be applied for the purpose of offset caging using the 2-wire method. The caging bias network consists of a three-position selector switch and a potentiometer. The magnitude of the offset caging angle depends on the setting of the potentiometer. The direction of offset caging (CW or CCW) is determined by the selector switch which connects the potentiometer to either the +15-VDC or -15-VDC supply. The middle position on the selector switch is an open position for use when using either normal caging or 3-wire offset caging.

The output of the pitch operational amplifier is applied to a dual channel full trigger circuit such that when the input signal is positive, an output signal is obtained from one of the trigger channels. When the input is negative, an output is obtained from the other channel. At input voltage levels very close to zero, neither trigger channel is energized.

Each output of the pitch full trigger circuit is connected to a relay driver. When a driver is energized, a set of relay contacts close, applying the 13 V $\underline{/0^\circ}$ phase voltage to the pitch gyro reference winding and the 13 V $\underline{/+90^\circ}$ phase voltage to the pitch gyro control winding, thus driving the gyro back to null. When the pitch error is of the opposite polarity, the other relay driver is energized and contacts of this relay apply the opposite phases to the control and reference windings of the gyro.

To prevent caging voltages from being applied to the gyros when they are being torqued, a cage enable circuit in the GSE must be energized prior to the application of any caging voltages. This interlock circuit, which consists of a driver pair, furnishes a ground to the emitters of the GSE roll, pitch, and yaw relay drivers when energized. The energizing of this circuit depends upon the cage switch on the GSE so that, when the switch is depressed, the torquing output circuit from the FACS is applied to the base of the driver pair. The logic of the torquing output circuit is positive when not torquing, and ground when torquing. This logic is used for turning the GSE cage enable driver pair on or off, respectively.

A lamp is provided to indicate a pitch null when caging. The pitch null indicator lamp is on when there is no output signal from either side of the full trigger circuit (i.e. gyro error is within torquing deadband).

GSE ROLL CAGING CHANNEL

The roll caging control channel is identical to the pitch caging control channel.

GSE YAW CAGING CHANNEL

The yaw caging control channel is identical to the pitch caging control channel.

ELECTRICAL MEASUREMENTS

The external +28-VDC current supplied to the FACS from the GSE is monitored. The metering circuit consists of an ammeter placed in series with position 2 of the Power Selector switch. In this position, the meter is reading the current drawn by the FACS in external power only. In the other two positions of the switch, the ammeter is out of the circuit.

There are twelve monitor test points for conveniently measuring pertinent FACS voltages. These voltages are as follows:

a. Pitch Error

b. Yaw Error

c. Roll Error

d. Slave Roll Error

e. 26-V Offset Reference

f. Battery

g. +28-VDC Buss

h. +15 VDC

i. -15 VDC

j. 26 V $\underline{/0^{\circ}}$

k. 26 V $\underline{/+90^{\circ}}$

l. Read-Out Return

The FACS GSE system incorporates a Measurement Selector switch which conveniently enables making AC ratio measurements of pertinent FACS control system voltages with external Ratiometer equipment* connected to the Ratiometer input jacks. These FACS control voltages are the roll, pitch and yaw error signals. The ratios of these signals are obtained with respect to the 26-V offset reference voltage which functionally is the 26 V $\underline{/0^{\circ}}$ phase of the static inverter.

In addition to conveniently arranging AC ratio measurements, the measurement selector switch also readily permits measuring many of the monitor test point voltages, and external DC or external AC voltages directly with the externally available Ratiometer equipment.

GSE INDICATION CIRCUITS

THE START POSITION INDICATOR lamp, when lit, indicates that the FACS programmer ledex is in position 12, the starting position. The programmer provides a +28-VDC signal when the ledex is in this position.

THE PROGRAM POSITION INDICATOR is a voltage measuring device that indicates the position of the programmer ledex switch. On one deck of the ledex there

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*This Ratiometer equipment is not part of the breadboard GSE.

are eleven 499 ohm ± 1% resistors, one placed across each of the twelve positions. Position one is connected to +5 VDC, and ground is connected to position twelve. Since the ledex arm is the output, the voltage at the indicator will vary from +5 VDC to ground in twelve equal increments.

THE ROLL, PITCH AND YAW (CW AND CCW) INDICATORS (six total) are enabled only when the Cage or Error Test switch is depressed. When either switch is depressed, any of the valve drivers that is energized causes its corresponding GSE indicator lamp to become lit.

THE ROLL, PITCH AND YAW NULL INDICATOR circuits use a two stage lamp driver for logic inversion. An "OR" gate preceding the lamp driver circuits causes the indicator lamp to go off if the gyro error signal exceeds the deadband established by the full trigger. When gyro error is within the deadband, the second stage of the lamp driver conducts and the lamp goes on. These indicator lamps indicate the null of the GSE caging channels only (not necessarily the gyro nulls).

THE SLAVE ROLL NULL INDICATOR indicates a null if both relays in the FACS slave roll control channel are de-energized. In this state, 26 V $\underline{/0^\circ}$ is applied to the GSE through K4 and K5 of the IACS control electronics for energizing the lamp.

THE SLAVE ROLL ARM INDICATOR circuit consists of two transistors whose logic is such that a ground at the IACS control electronics slave roll drivers energizes the lamp. This indicator is on when the Cage switch is depressed or when slave roll is armed.

THE DESPIN INDICATOR circuit includes two transistors and an indicator lamp. The two transistors operate as a logic "AND" circuit. Before and during coast time delay, the arm roll and despin lines are grounded, keeping the lamp driver de-energized. Immediately after the coast time delay, and prior to turn-off of the despin valve, the arm roll and despin lines are at +28 VDC, energizing the driver and lamp. After vehicle despin valve turn-off, arm roll is at +28 VDC and the despin line is at ground, de-energizing the lamp driver. The lamp therefore, when energized, indicates that the FACS circuit condition is that prevailing during despin.

THE TORQUING INDICATOR circuit includes a two stage lamp driver that requires a ground signal input for energizing the lamp. When an FACS gyro is being torqued, a relay closure in the programmer provides a ground signal to the Torquing indicator, energizing the lamp. When not torquing, a +15-VDC signal is received which causes the lamp to remain de-energized. This torquing signal is also used to generate a logic gate used in the Maneuver Direction and Maneuver Axis indicator circuits.

THE ROLL CAPTURE INDICATOR circuit includes a two transistor lamp driver that requires a +28-VDC signal input for energizing the lamp. When the FACS is captured in roll, K3 (in the IACS control unit) energizes, providing a +28-VDC signal to the transistors. When not in roll capture, the signal from K3 is a ground, causing the lamp to remain de-energized.

THE PITCH AND YAW CAPTURE INDICATORS each consist of an indicator lamp in series with a limiting resistor. One side of both lamps is tied to ground, so that a +28-VDC signal is required to energize these lamps. When the FACS is captured in either pitch or yaw, relay closures in the FACS provide a +28-VDC signal to the particular indicator.

THE ROLL, PITCH AND YAW MANEUVER INDICATORS are single transistor lamp drivers that are gated with two functions. One gate input is received when the programmer ledex is in the particular maneuver position and the other when the FACS is torquing. The torquing gate is generated by the Torquing indicator circuit. When the FACS is torquing, this circuit provides a ground to the emitters of the Maneuver indicator circuit drivers enabling them to energize when a +28-VDC maneuver signal appears at the input to the driver base circuit.

THE CW AND CCW MANEUVER DIRECTION INDICATORS are gated by the torquing gate logic. When the torquing gate is present, the Maneuver Direction lamp drivers have their emitters grounded. A +28-VDC signal is received for a CCW maneuver or an open circuit for a CW maneuver.

THE SACS OPERATING INDICATOR is a two transistor lamp driver. The input required to energize the lamp is a positive signal provided from the SACS when the system has received its start signal. With the SACS inoperative, the output of this line is near ground.

THE TORQUE LOOP CLOSURE INDICATOR uses a two stage lamp driver for logic inversion. Torque loop closure is indicated by the application of a ground signal when K5 in the SACS is energized. With K5 de-energized +28 VDC is applied to the first stage, holding the lamp de-energized.

THE PITCH LOW-THRUST (CW, CCW AND NULL) INDICATOR circuits consist of three lamps, in addition to logic diodes and a single transistor operating as a logic "NOR" circuit. When a low thrust CW valve is active in the SACS, a ground is applied to the pitch CW lamp, which becomes energized, and also to one of the gates. The "NOR" transistor, being inhibited by the presence of a ground at one of the gates, causes the Null lamp to remain de-energized. For a CCW valve, the logic process is the same. When no valves are active, both CW and CCW lamps are off and the inputs to the "NOR" circuit are appropriate for energizing the "NOR" transistor, causing the Null lamp to become lit.

THE YAW LOW-THRUST (CW, CCW AND NULL) INDICATOR circuits are identical to those in the pitch indicator circuits described above.

THE SACS PITCH AND YAW TORQUE NULL INDICATOR circuits each consists of an indicator lamp in series with a limiting resistor. The null indicator energizes with the application of 26 V $\angle 0^\circ$ which is provided by the SACS when both relays K2 and K3 (or K7 and K8) are de-energized. The relays in this state represent a pitch (or yaw) torque null.

THE LOW/HIGH THRUST ENABLE INDICATOR circuits include two stage lamp drivers for controlling indicator lamps. With SACS relays K4 (for pitch) and K6 (for yaw) de-energized, the pitch and yaw high thrust enable-indicator drivers are energized by the low thrust driver collectors due to the absence of signal at the input of the low thrust driver. When the relays energize, +28 VDC is applied to the low thrust enable-indicator drivers energizing them and turning the high thrust drivers off.

NOTE

The test cable, as well as the umbilical cable, must be connected to the FACS in order to monitor SACS functions.

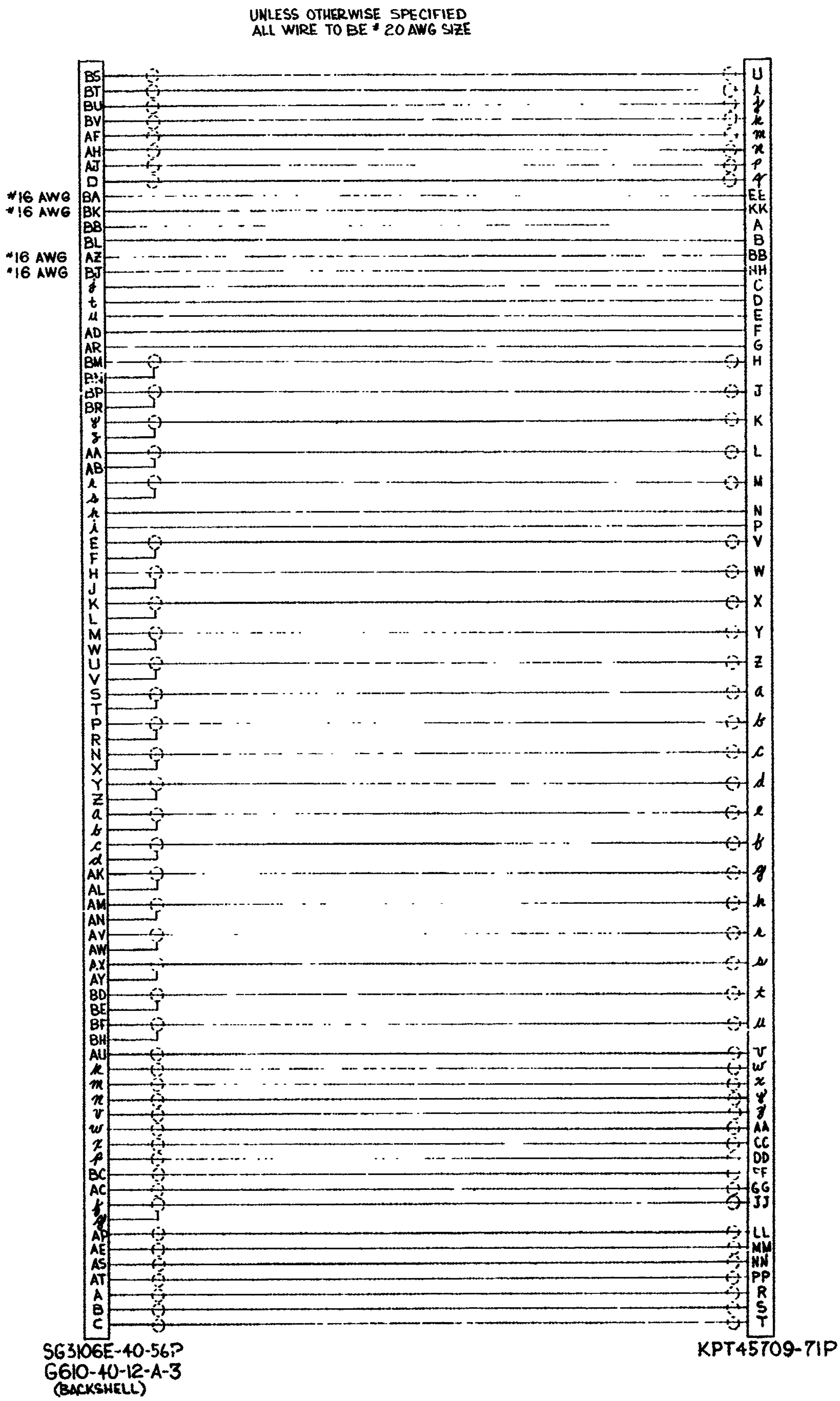
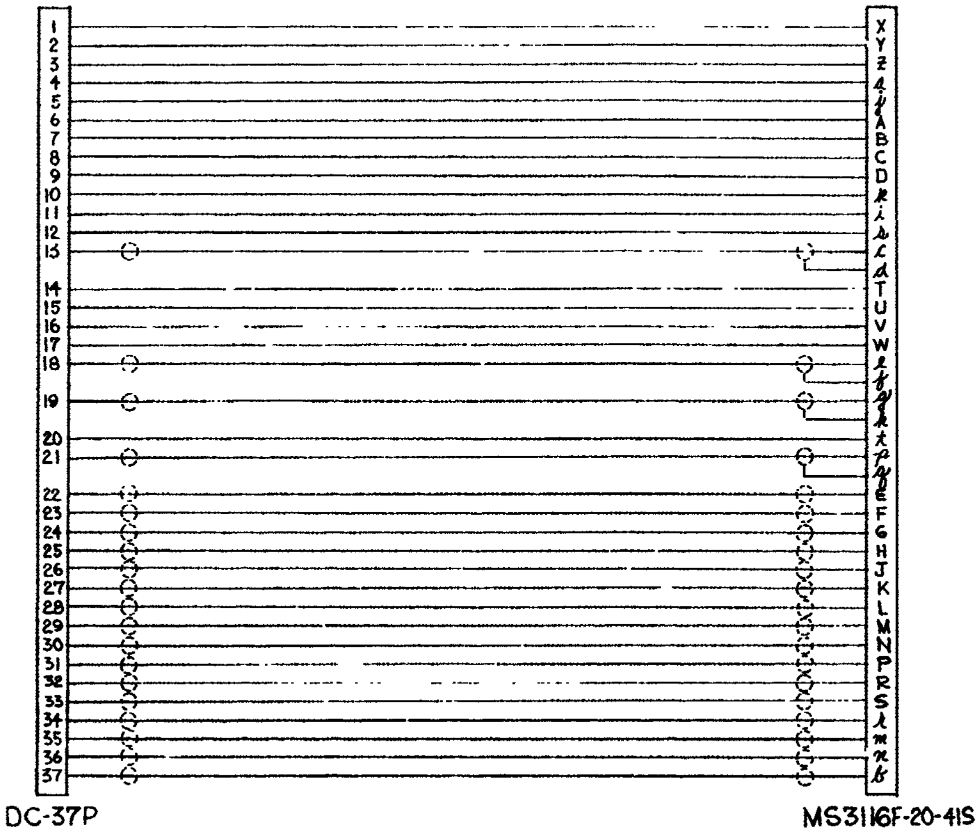


Figure I-15. Schema

UNLESS OTHERWISE SPECIFIED
ALL WIRE TO BE # 20 AWG SIZE



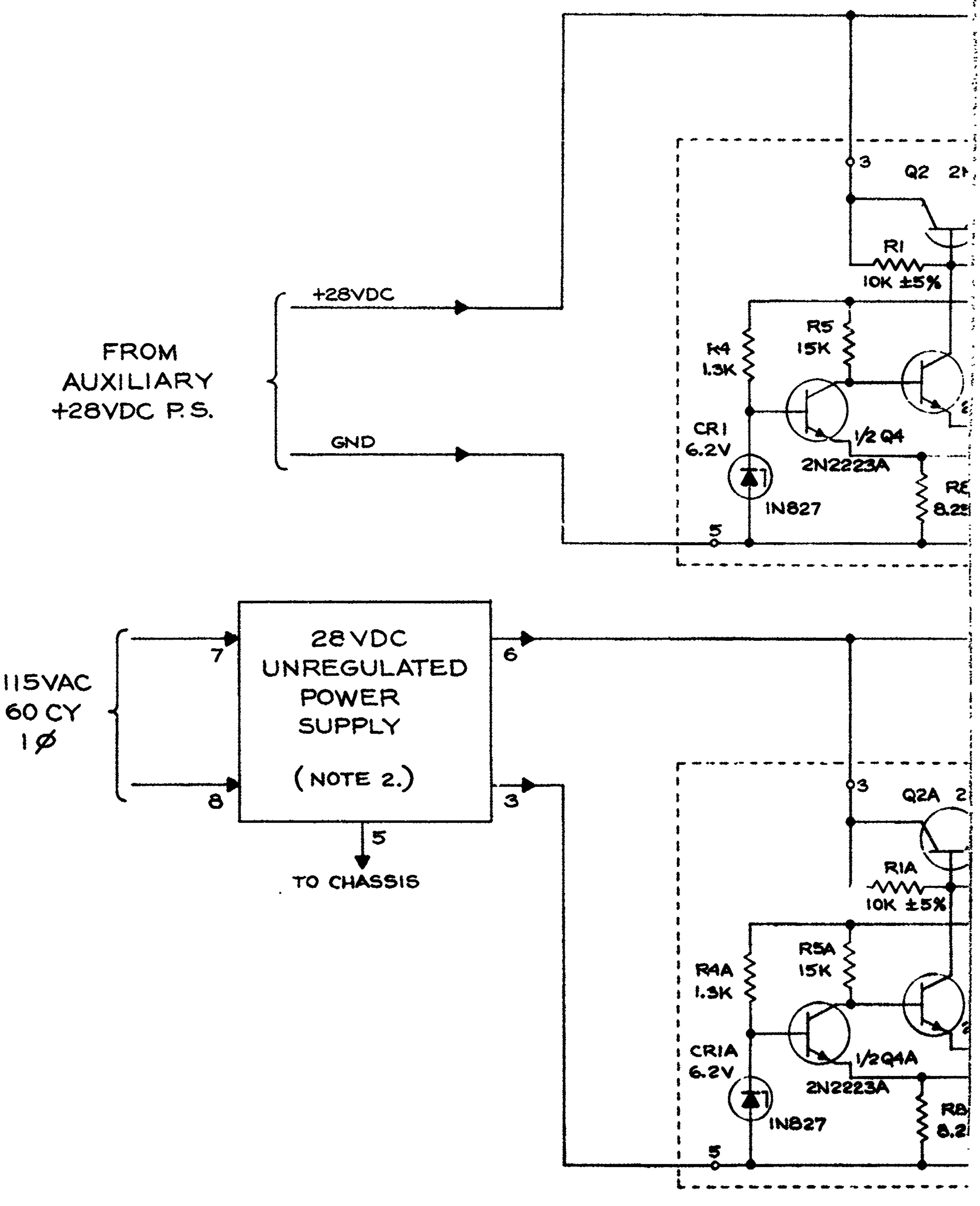
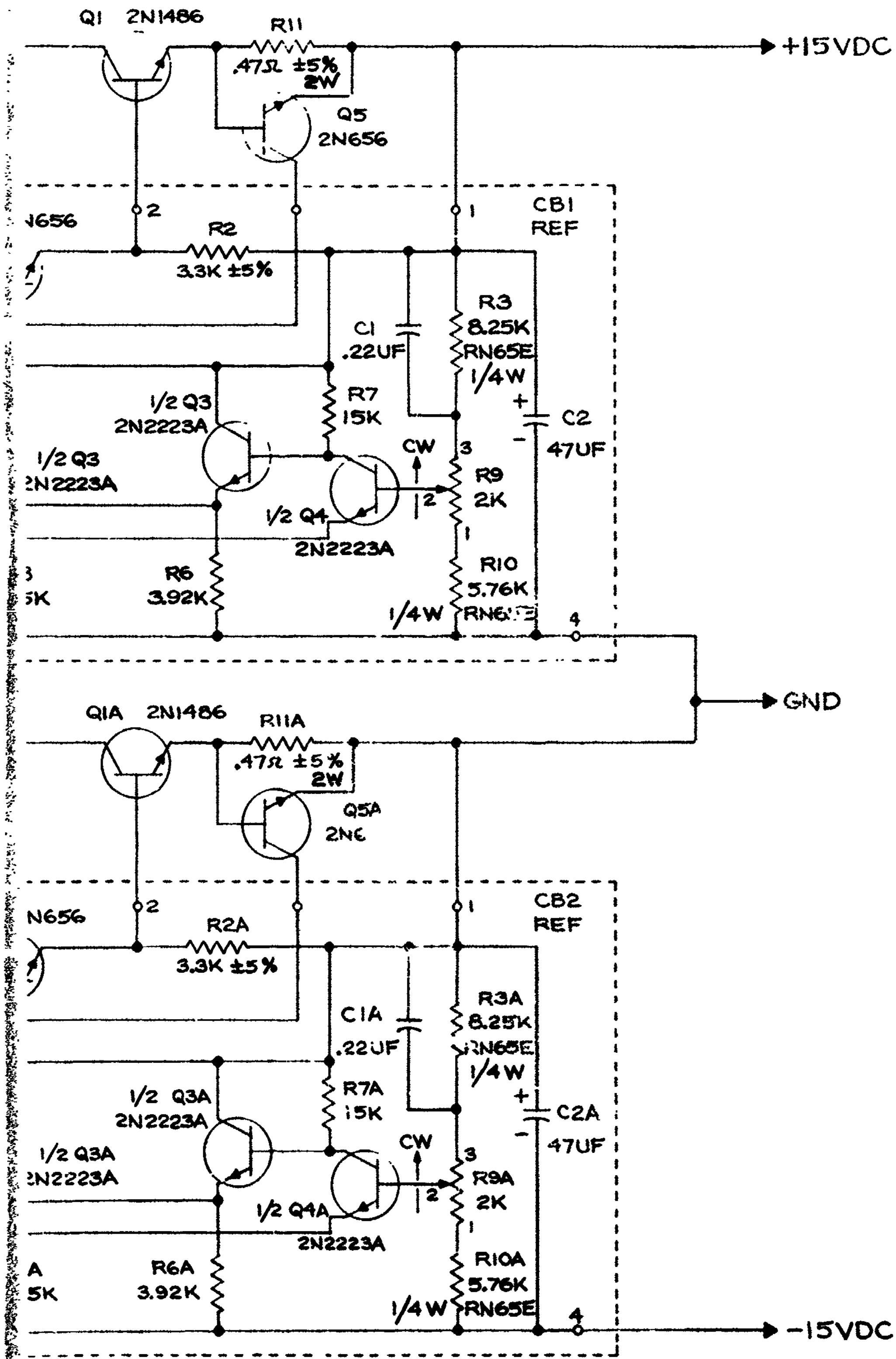


Figure I-16. Schematic, GSE DC Power Sup



ply (Sketch 742-D-20)

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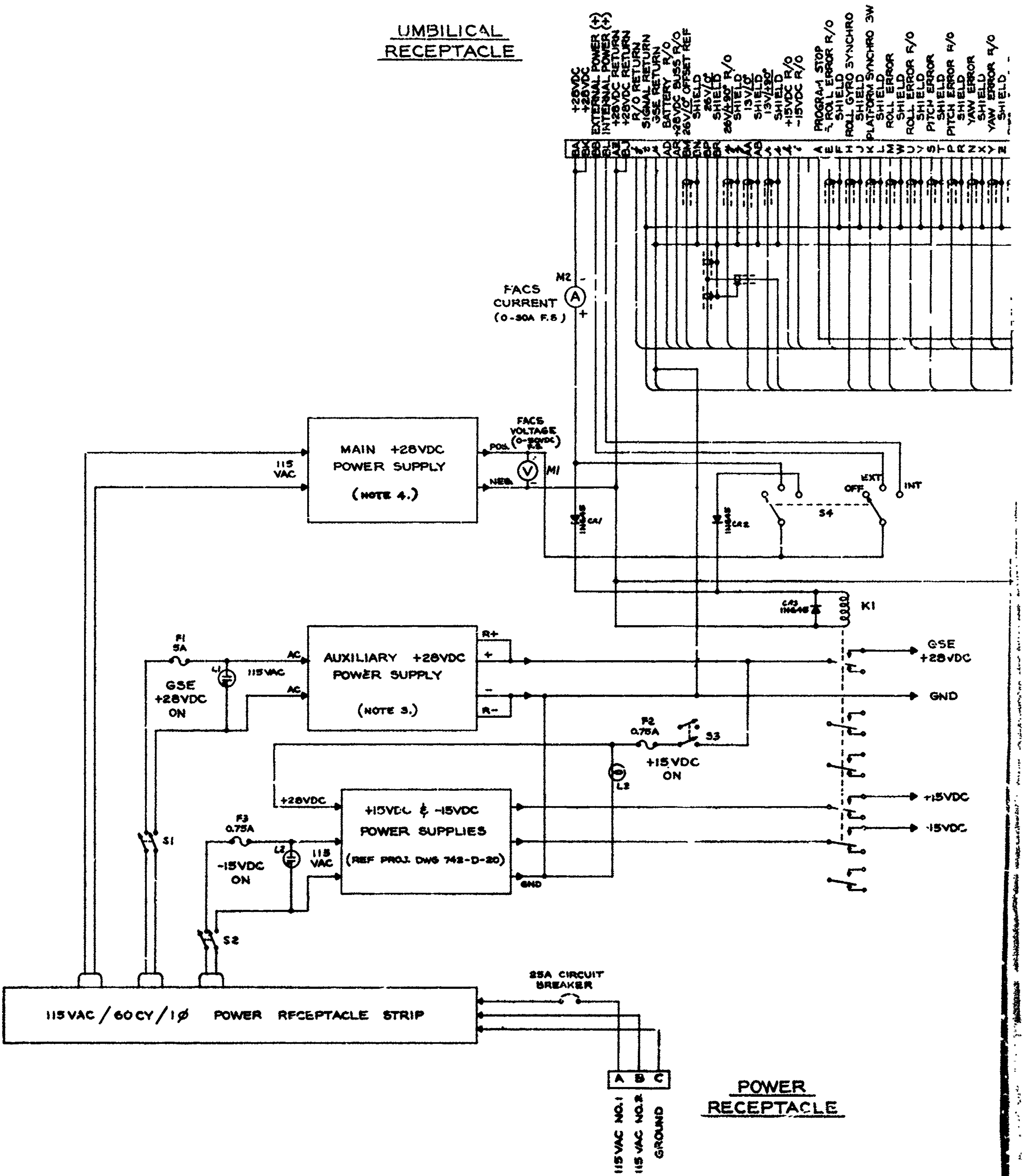
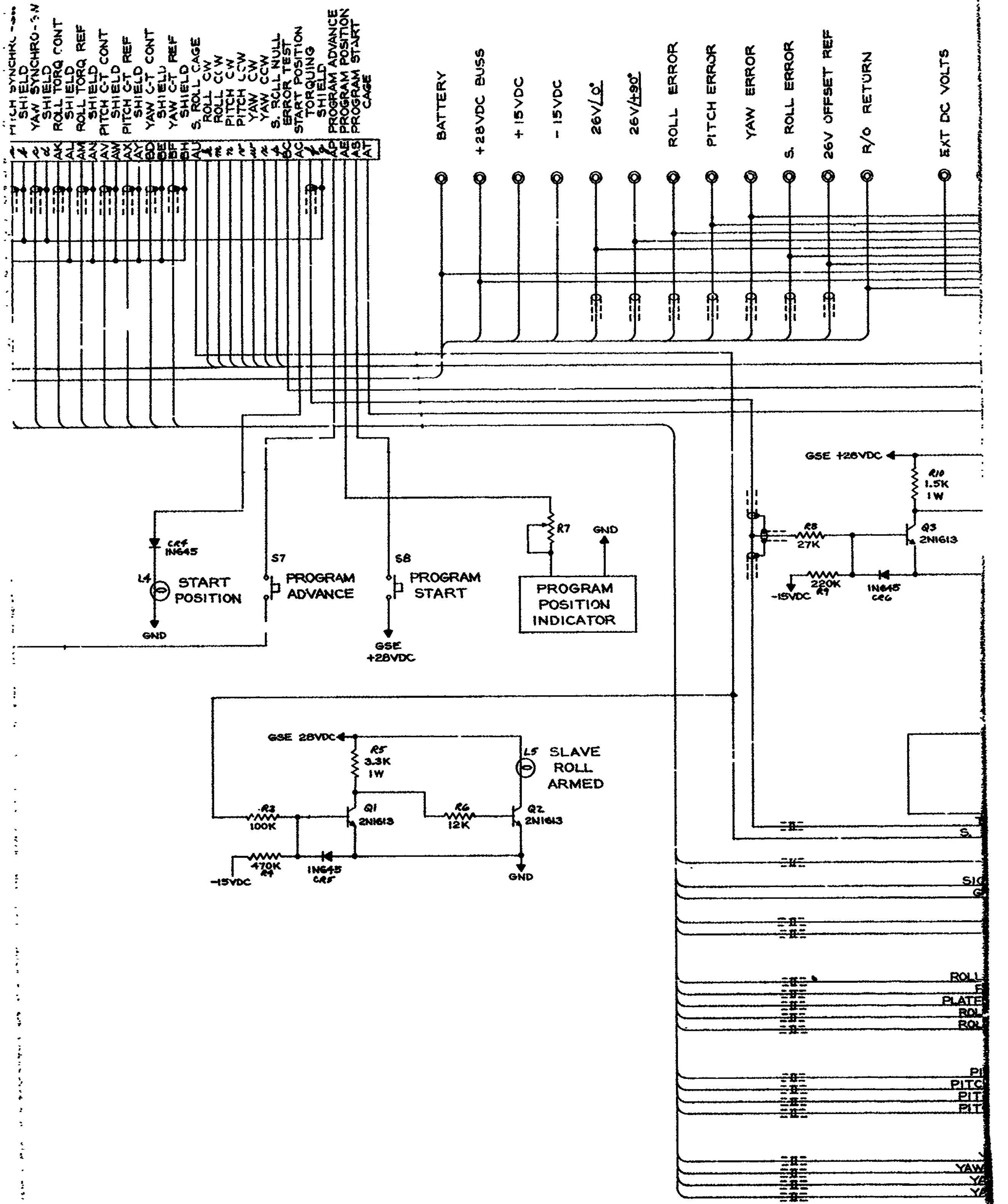
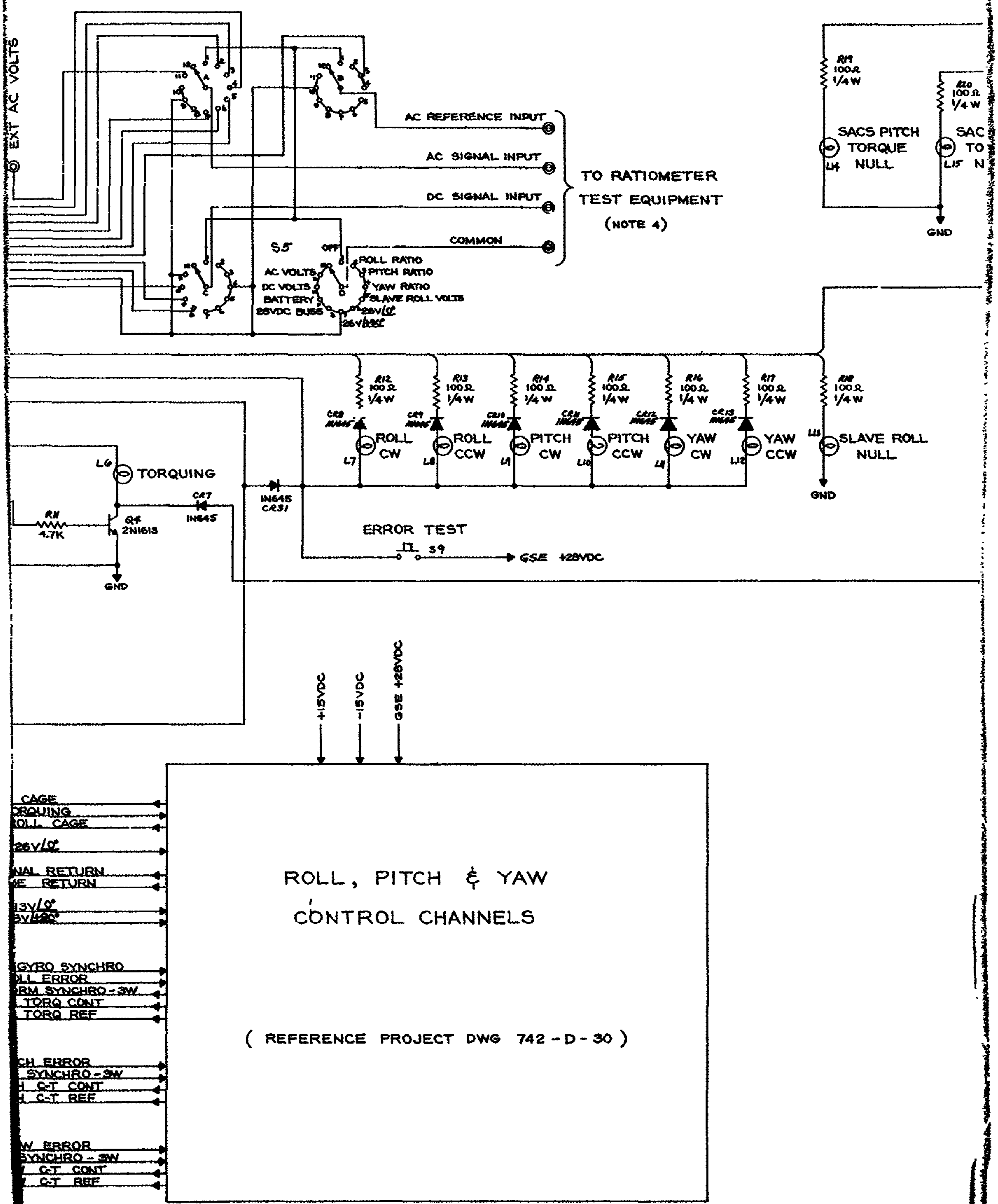


UMBILICAL RECEPTACLE
+28VDC
+28VDC
EXTERNAL POWER (+)
INTERNAL POWER (+)
+28VDC RETURN
+28VDC RETURN
R/O RETURN
SIGNAL RETURN
GSE RETURN
BATTERY R/O
+28VDC BUSS R/O
26V/0° OFFSET REF
SHIELD
26V/0°
SHIELD
SHIELD
13V/0°
SHIELD
SHIELD
+15VDC R/O
-15VDC R/O
PROGRAM STOP
ROLL ERROR R/O
SHIELD
ROLL GYRO SYNCHRO
SHIELD
PLATFORM SYNCHRO 3W
SHIELD
ROLL ERROR
SHIELD
ROLL ERROR R/O
SHIELD
PITCH ERROR
SHIELD
PITCH ERROR R/O
SHIELD
YAW ERROR
SHIELD
YAW ERROR R/O
SHIELD
M2
FACS CURRENT
(0-30A F.S.)
MAIN +28VDC POWER SUPPLY
(NOTE 4.)
115 VAC
POS.
NEG.
FACS VOLTAGE
M1
CR1
CR2
S4
OFF
EXT
INT
K1
CR3
F1
5A
L1
115VAC
AC
GSE +28VDC ON
AUXILIARY +28VDC POWER SUPPLY
(NOTE 3.)
R+
R-
GSE +28VDC
GND
F2
0.75A
S3
+15VDC ON
L3
+28VDC
+15VDC & -15VDC POWER SUPPLIES
(REF PROJ. DWG 742-D-20)
+15VDC
-15VDC
F3
0.75A
L2
-15VDC ON
115 VAC
GND
S1
S2
25A CIRCUIT BREAKER
115VAC / 60CY / 1∅ POWER RECEPTACLE STRIP
A
B
C
115 VAC NO.1
115 VAC NO.2
GROUND
POWER RECEPTACLE

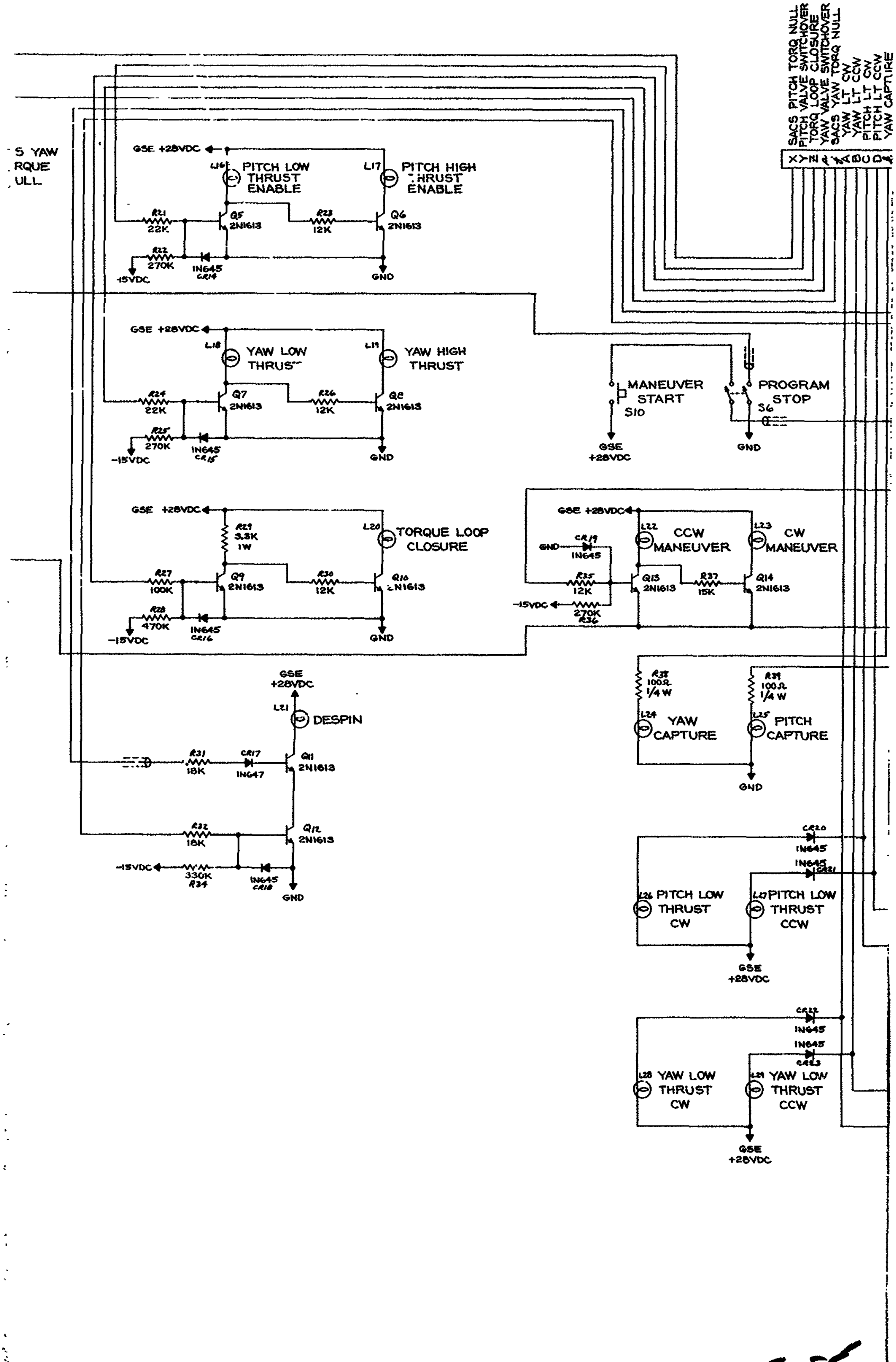

PITCH SYNCHRO
SHIELD
YAW SYNCHRO
SHIELD
ROLL TORQ CONT
SHIELD
ROLL TORQ REF
SHIELD
PITCH C-T CONT
SHIELD
PITCH C-T REF
SHIELD
YAW C-T CONT
SHIELD
YAW C-T REF
SHIELD
S. ROLL CAGE
ROLL CW
ROLL CCW
PITCH CW
PITCH CCW
YAW CW
YAW CCW
S. ROLL NULL
ERROR TEST
START POSITION
TORQUING
SHIELD
PROGRAM ADVANCE
PROGRAM POSITION
PROGRAM START
CAGE
AK
AL
AM
AN
AV
AW
AX
AY
BD
BE
BF
BH
AU
BC
AC
AD
AE
AS
AT
BATTERY
+28VDC BUSS
+15VDC
-15VDC
26V/0°
26V/+90°
ROLL ERROR
PITCH ERROR
YAW ERROR
S. ROLL ERROR
26V OFFSET REF
R/O RETURN
EXT DC VOLTS
GSE +28VDC
R10
1.5K
1W
R8
27K
Q3
2N1613
220K
R9
-15VDC
1N645
CR6
CR4
1N645
L4
START POSITION
GND
S7
PROGRAM ADVANCE
S8
PROGRAM START
GSE
+28VDC
R7
GND
PROGRAM POSITION INDICATOR
GSE 28VDC
R5
3.3K
1W
L5
SLAVE ROLL ARMED
R3
100K
Q1
2N1613
R6
12K
Q2
2N1613
470K
R4
-15VDC
1N645
CR5
GND
S.
SIG
ROLL
PLATE
ROL
ROL
PI
PITC
PIT
PIT
YAW
YA
YA

Figure

I-55 (2)

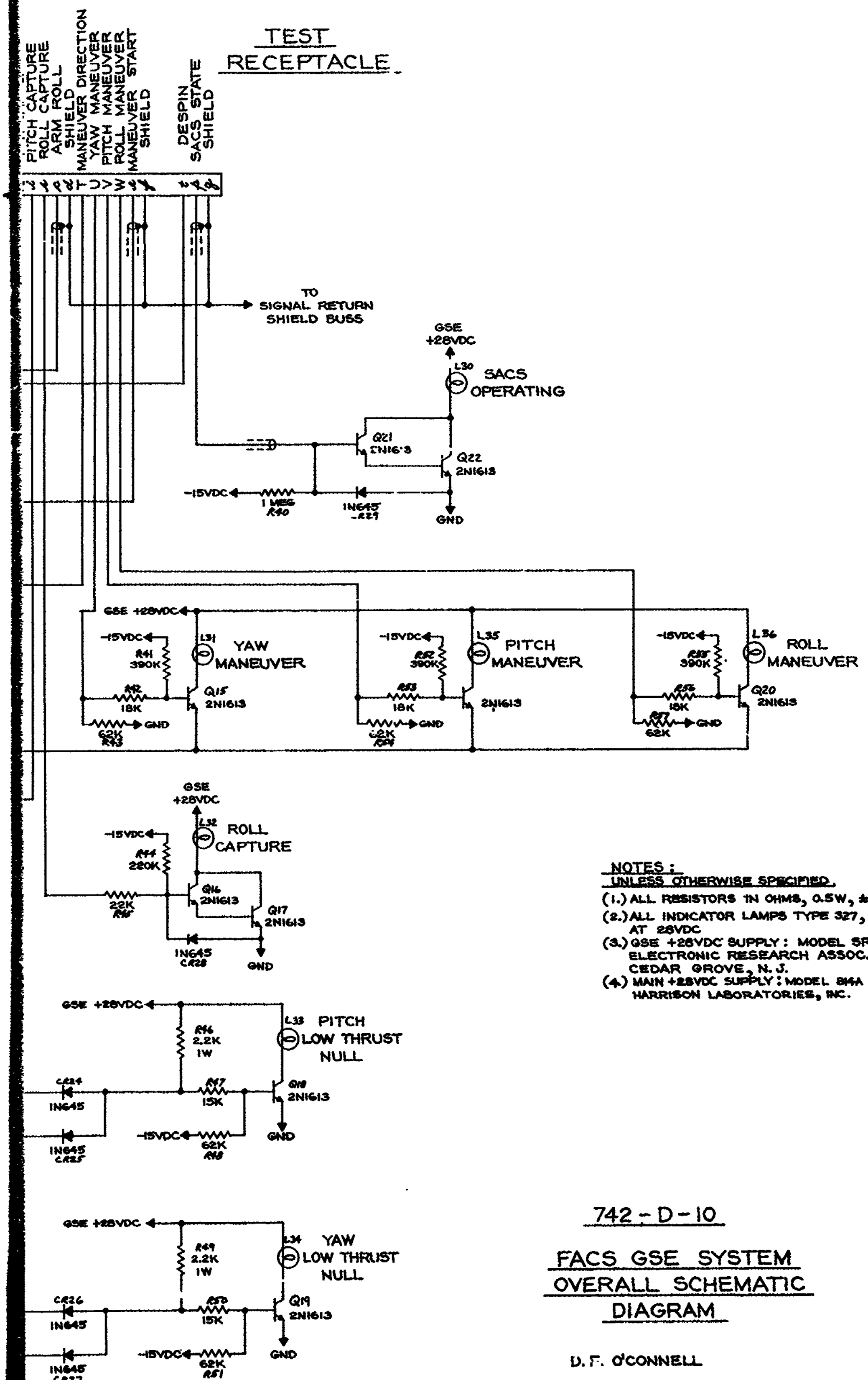


I-17. Schematic, Overall GSE (Sketch 742-D-10)



SACS PITCH TORQ NULL
PITCH VALVE SWITCHOVER
TORQ LOOP CLOSURE
YAW VALVE SWITCHOVER
SACS YAW TORQ NULL
YAW LT CW
YAW LT CCW
PITCH LT CW
PITCH LT CCW
YAW CAPTURE
S YAW
RQUE
ULL
GSE +28VDC
PITCH LOW THRUST ENABLE
PITCH HIGH THRUST ENABLE
YAW LOW THRUST
YAW HIGH THRUST
TORQUE LOOP CLOSURE
MANEUVER START
S10
PROGRAM STOP
S6
CCW MANEUVER
CW MANEUVER
YAW CAPTURE
PITCH CAPTURE
DESPIN
PITCH LOW THRUST CW
PITCH LOW THRUST CCW
YAW LOW THRUST CW
YAW LOW THRUST CCW
2N1613
1N645
1N647
-15VDC
GND

I-55



NOTES:
UNLESS OTHERWISE SPECIFIED.
(1.) ALL RESISTORS IN OHMS, 0.5W, ±5%
(2.) ALL INDICATOR LAMPS TYPE 327, 0.04A AT 28VDC
(3.) GSE +28VDC SUPPLY: MODEL SR264 ELECTRONIC RESEARCH ASSOC. INC. CEDAR GROVE, N.J.
(4.) MAIN +28VDC SUPPLY: MODEL 814A HARRISON LABORATORIES, INC.

742-D-10

FACS GSE SYSTEM OVERALL SCHEMATIC DIAGRAM

D. F. O'CONNELL

21 SEPT. 1964

REVISED:
30 OCT. 1964
21 DEC. 1964
22 FEB 1965
4 JUNE 1965 PHASE I FINAL

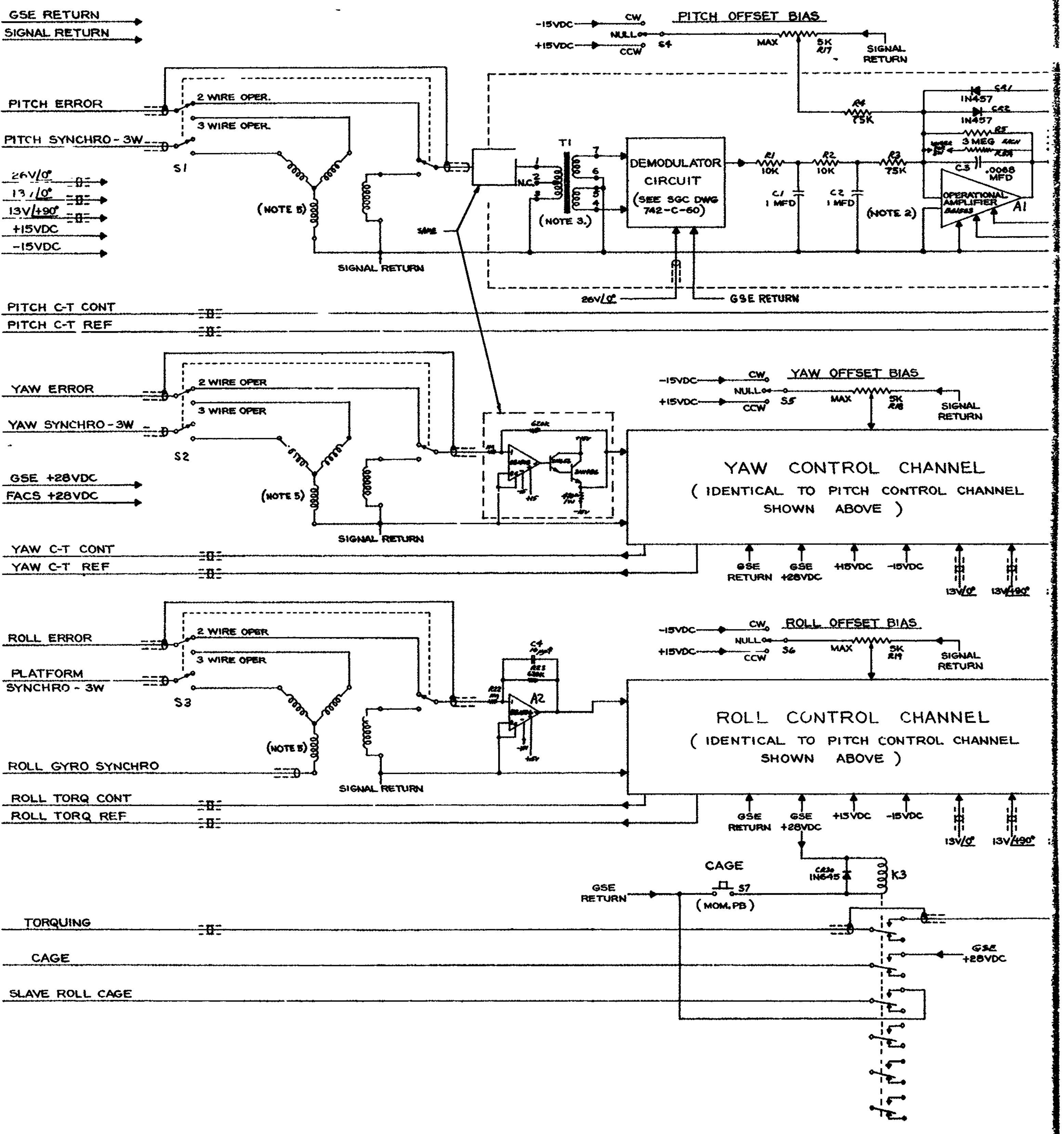
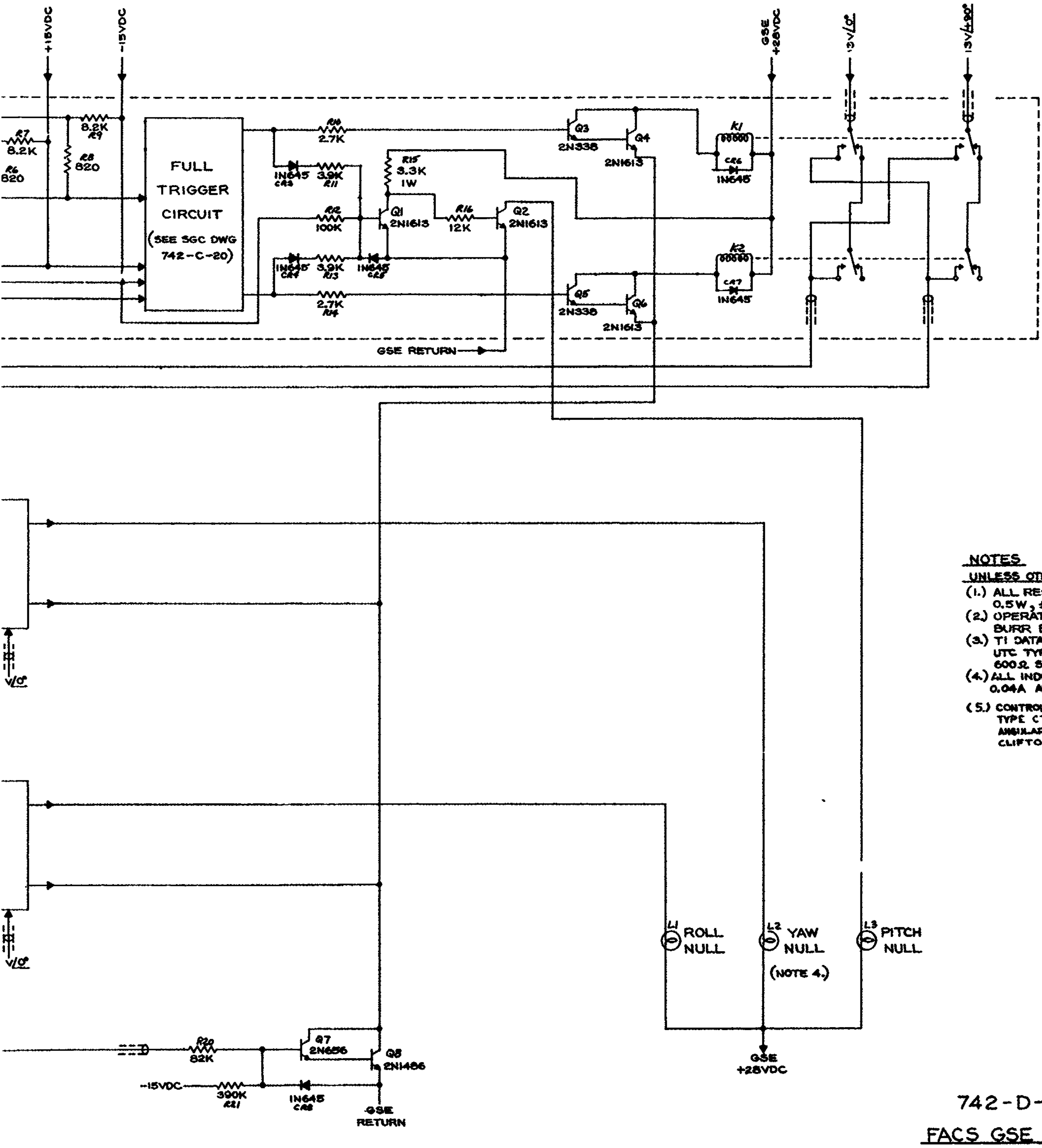


Figure I-18. Schematic, GSE Caging Contro



NOTES
UNLESS OTHERWISE SPECIFIED:
(1.) ALL RESISTORS IN OHMS, 0.5W, ±5%.
(2.) OPERATIONAL AMPLIFIERS BURR BROWN MODEL 1503.
(3.) T1 DATA : TYPE M690007-1, UTC TYPE W-790, 24K CT PRI, 600Ω SPLIT SEC.
(4.) ALL INDICATOR LAMPS TYPE 327, 0.04A AT 28VDC
(5.) CONTROL TRANSFORMER. TYPE CTH-15-D-5 WITH MINIATURE ANGULAR POSITIONING ASSEMBLY CLIFTON PRECISION PRODUCT

742-D-30
FACS GSE SYSTEM
CAGING CONTROL CHANNELS
SCHEMATIC DIAGRAM

D. F. O'CONNELL
30 SEPT 1964
REVISED:
2 NOV 1964
22 DEC 1964
4 JUNE 1965 PHASE I FINAL

. Channels (Sketch 7-2-D-30)

(2)

K. FULL TRIGGER/HALF TRIGGER

The triggers designed for the FACS have stable triggering points with trigger hysteresis within well defined limits. With very little hysteresis, the valves will tend to chatter, and with excessive hysteresis the control dynamics will be adversely affected. A standard Schmitt trigger tends to have a somewhat unpredictable hysteresis, and its trigger point is temperature-dependent. A differential amplifier with a fixed reference voltage as one input can be used as a stable comparator. Thus, the trigger point of the trigger can be primarily determined by the differential amplifier when used as a comparator. The output of the comparator can then be coupled to a more or less standard Schmitt trigger. The system triggers are designed in this way (see Figures I-19 and I-20). The 2N2223A transistor is especially designed for differential amplifier applications, and this transistor is used for the comparator. Thus, a stable and predictable trigger point is assured. In addition, the trigger hysteresis can be changed by changing the voltage gain of the comparator. This is most easily accomplished by changing the values of resistors R2 and R3 between the emitters of the 2N2223A transistor Q1. Essentially the same trigger is used for negative input voltages as is used for positive input voltages. This flexibility is readily possible due to the versatility of the differential amplifier connection.

With a zero-volt input signal, transistor Q1 is off and transistor Q2 is on. The collector of Q2 is at approximately zero volts, transistor Q5 is off, and transistor Q6 is on. The voltage at the collector of Q6 is approximately 4 volts. Zener diode CR3 does not conduct, and the trigger output signal is at zero volts. As the input signal increases positively, transistor Q1 begins to conduct when the base voltage of transistor Q1 approaches the base voltage of transistor Q2. The sum of the collector currents of Q1 and Q2 is always essentially constant. As transistor Q1 begins to conduct, transistor Q2 starts to turn off, and the collector voltage of Q2 increases. Transistor Q5 is turned on when the voltage at the base of Q1 is approximately equal to the voltage at the base of Q2. At this time the trigger exhibits an output signal. Since the voltage at the base of transistor Q2 is adjustable, the trigger point is adjustable. Transistors Q5 and Q6 with the associated resistors comprise a standard Schmitt trigger. Zener diode CR3 is used to make the output zero volts when transistor Q6 is on. Otherwise, the no-output condition would be +4 VDC. Resistor R15 and diode CR5 clamp the output to zero volts or a slightly negative voltage even in the presence of normal leakage currents through Zener diode CR3.

For negative input signals which approach the magnitude of the voltage at the base of transistor Q4, transistor Q3 begins to turn off from its normally saturated state. The negative trigger exhibits an output when the voltage at the base of Q3 is approximately equal to the voltage at the base of Q4.

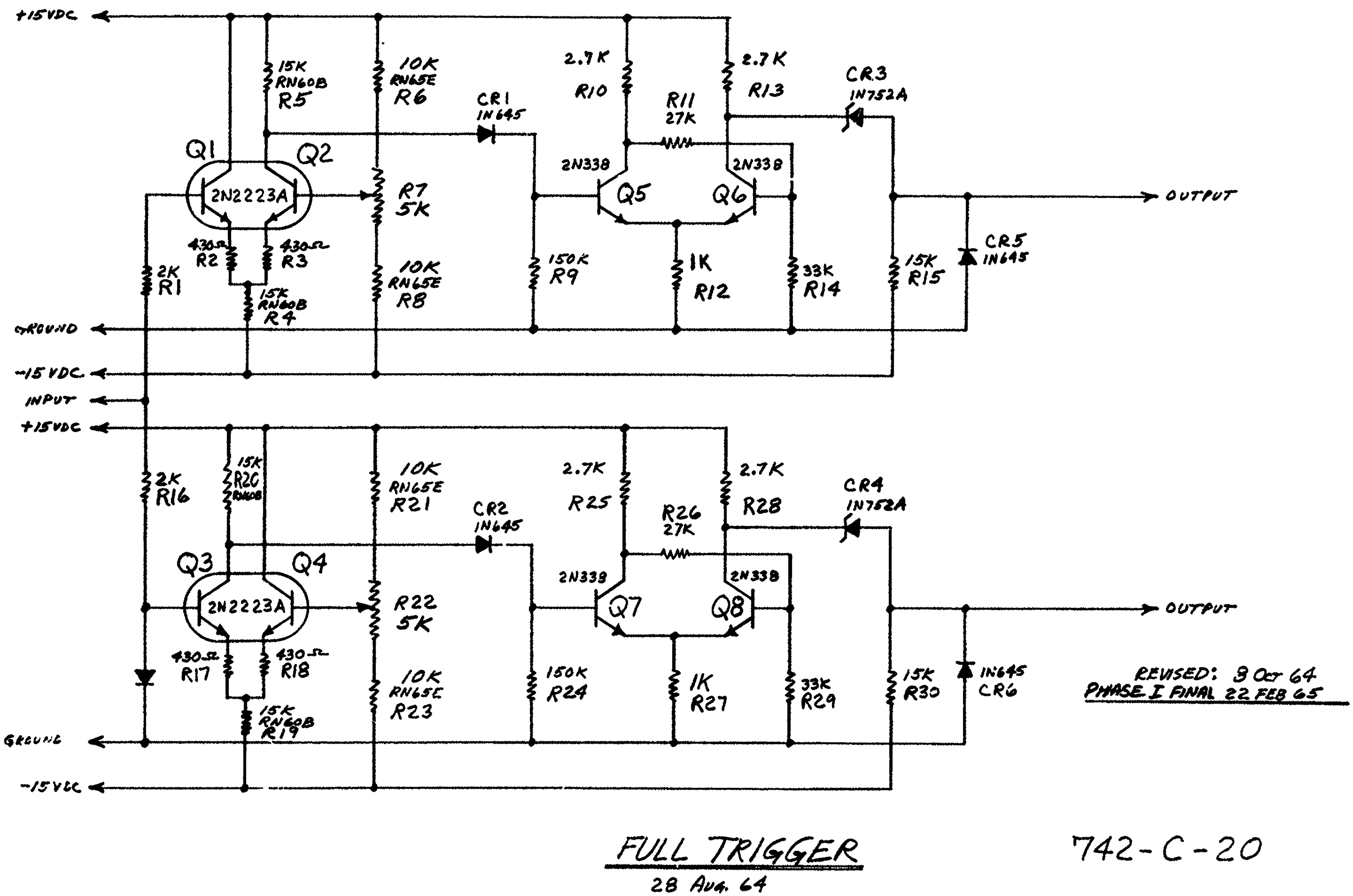
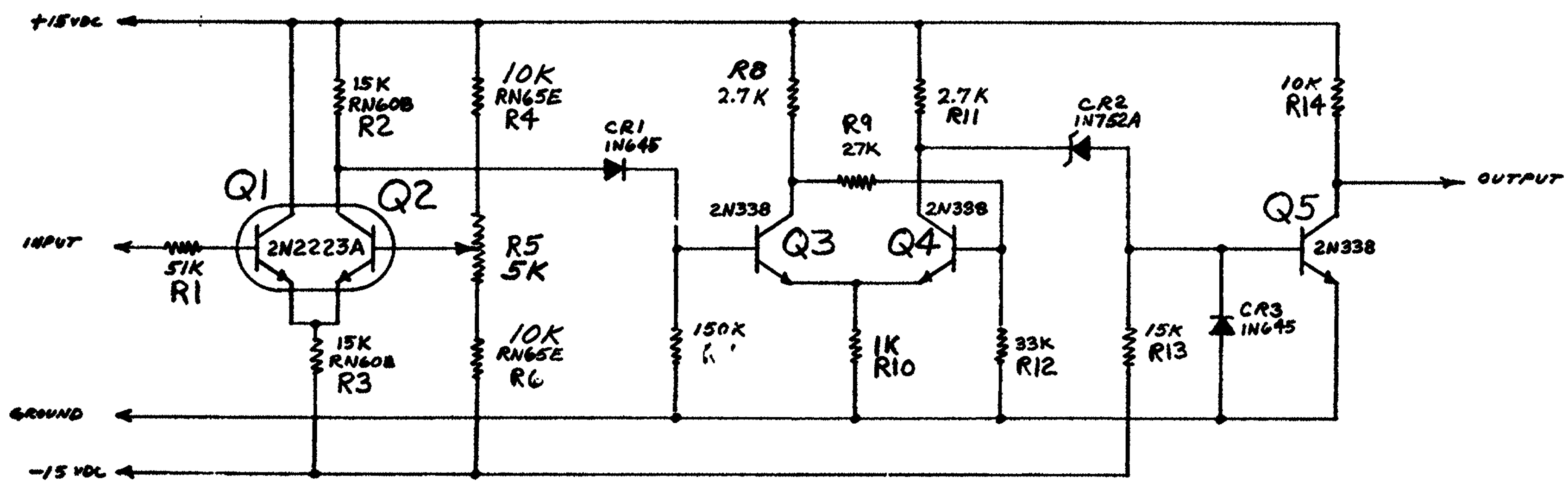


Figure I-19. Schematic, Full Trigger (Sketch 742-C-20)



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HALF TRIGGER
28 AUG. 64

742-C-21

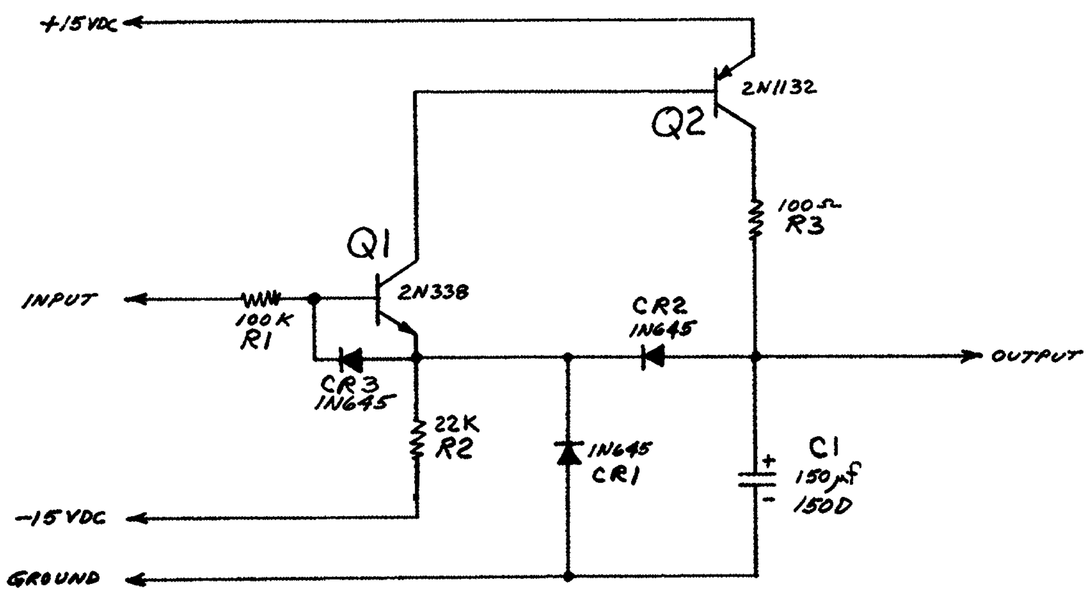
Figure I-20. Schematic, Half Trigger (Sketch 742-C-21)

L. ABSOLUTE VALUE CIRCUIT

A change in gain occurs in the system when the vehicle error decreases below about 2.0°. However, the switchover to the limit cycle mode, which occurs at this time, should not occur if the vehicle rate is too high. A two transistor (Q1 and Q2) absolute value circuit is included as part of the logic trigger to prevent a capture signal when the vehicle goes through a zero-position error point with a high rate (see Figure I-21).

Position-gyro synchro signals are coupled to the absolute value circuit at resistor R1. Transistor Q1 is sensitive only to the positive half cycles of the input signal. Resistor R1 establishes a high input impedance and limits the base current of transistor Q1. During the positive half cycle of the input signal, transistor Q1 draws base current, and therefore collector current, causing transistor Q2 to draw collector current also. The collector current of transistor Q2 is essentially equal to $(\beta_1)(\beta_2)(I)_{in}$. The collector current of transistor Q2 causes capacitor C1 to charge toward a positive voltage. During the negative half-cycle of the input signal, transistor Q2 is turned off. Capacitor C1 then begins to discharge through resistor R2 toward -15 VDC. However, the time constant is such that the amount of discharge is insignificant during the half-cycle (of 400 cycles) that transistor Q2 is turned off. As capacitor C1 attains a positive charge, transistor Q1 conducts for a progressively shorter portion of the input signal period because the emitter of Q1 is biased up by the capacitor voltage. The steady-state value is attained when capacitor C1 has charged to the peak value of the input signal. If the input signal is interrupted or caused to decrease rapidly, the capacitor discharges through resistor R2 until the input signal reappears or until the trigger point of the logic trigger is reached. This is the point where a capture signal occurs. However, if the amplitude of the position gyro signal should increase sufficiently before the logic trigger point is reached, the capacitor again charges up and no capture signal occurs. This method reduces unnecessary gain changes and relay chatter prior to valid vehicle capture. In addition, overshoots are minimized.

Diode CR1 clamps the emitter of transistor Q1 to ground, preventing negative voltages at the emitter of Q1. Diode CR2 is used to prevent transistor Q1 from charging capacitor C1 directly. Resistor R3 is used to limit the maximum collector current of transistor Q2. The time required for capacitor C1 to discharge from +15 VDC to the trigger level of the logic trigger is about 2.1 seconds.



REVISED: 8 OCT 64 PHASE I FINAL

742-C-40

ABSOLUTE VALUE CIRCUIT

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Figure I-21. Schematic, Absolute Value Circuit (Sketch 742-C-40)

M. BUFFER AMPLIFIER

The rate gyros must be loaded, for optimum operation, with a fixed, resistive impedance of 10,000 ohms. A one transistor buffer amplifier is used to couple the output of each rate gyro to a demodulator circuit (see Figure I-22).

The input impedance of the amplifier is determined primarily by resistors R1 and R2 with only a second order effect from the input impedance of transistor Q1. Capacitor C1 is used to decouple the DC voltage at the base of Q1 from the rate gyro. The value of C1 was chosen so that the capacitive reactance at 400 cycles would be negligible in comparison to the input impedance of the amplifier. Resistors R1, R2, and R3 set a DC operating point of about +2 VDC at the output of transistor Q1. A slightly positive operating point was chosen to bias the polarized capacitors C1 and C2 properly. The value of capacitor C2 is such that the capacitive reactance at 400 cycles is negligible compared to the input impedance of the demodulator.

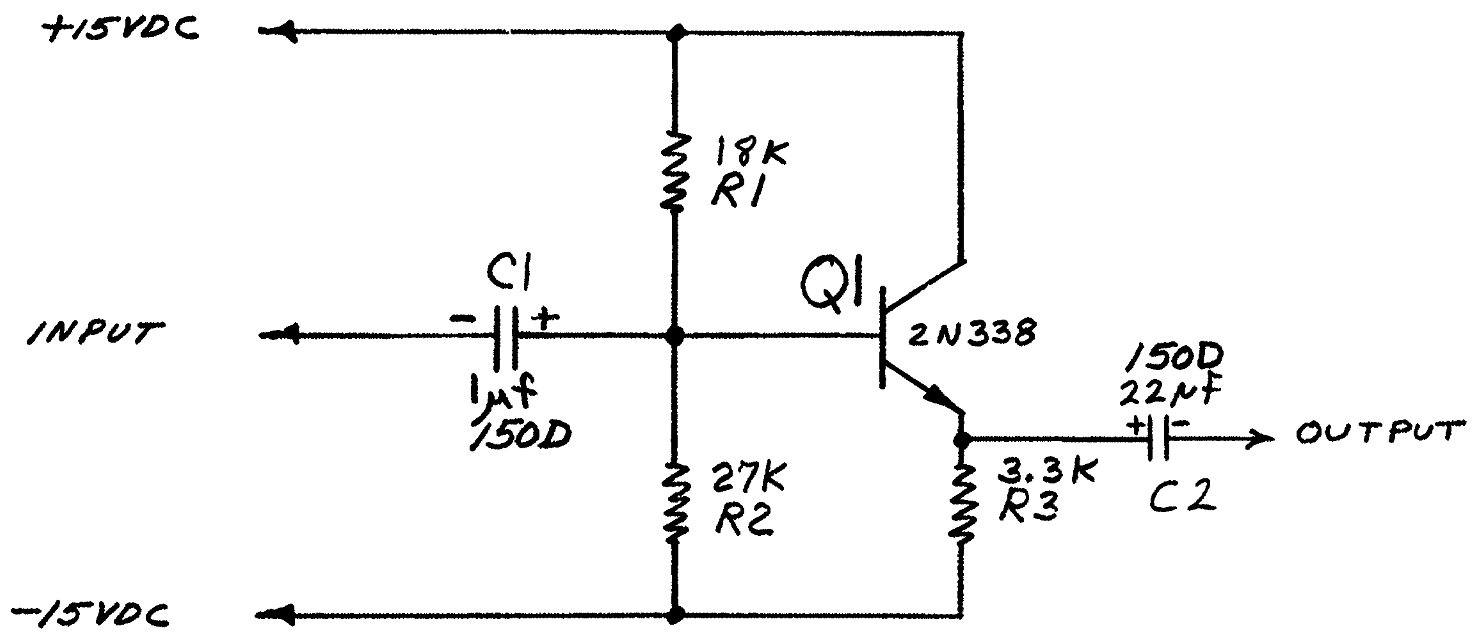


Figure I-22. Schematic, Buffer Amplifier (Sketch 742-C-50)

N. DEMODULATOR

The demodulator is used to convert the position and rate gyro signals, which are 400-cycle sine-wave voltages, to full-wave rectified signals. The demodulated signal is then filtered to obtain a DC voltage the amplitude of which is proportional to the gyro output signal. The polarity of the DC signal is dependent on the phase of the gyro error signal. A schematic of the demodulator is shown in Figure I-23.

Reference for the demodulator is obtained from the static inverter 26-VAC zero phase. The required base current limiting resistance for the 2N498 transistors (Q1, Q2, Q3, and Q4) is in series with the secondary windings of the reference transformer T1. Four transistor switches are used in the demodulator, and the operation requires that two of the switches be closed while two are open. Four transistors are used instead of two because the saturation voltages of the transistors can be made to very nearly cancel if the transistors are matched in pairs. Thus, it is possible to detect lower amplitude signals with the four transistor demodulator. In addition to a lower offset voltage, the output signal from the four transistor combination is less temperature-dependent than the two transistor equivalent. Diodes CR1, CR2, CR3, and CR4 are used from the base to the emitter of each transistor to protect it from reverse voltages which occur each half-cycle of the reference voltage.

Operation of the demodulator can be explained by postulating an input signal which is in phase with the reference voltage. During the positive half-cycle of the reference signal, base current flows through transistors Q1 and Q2, and these transistors are switched into the on condition. At this time the emitter-to-base junctions of transistors Q3 and Q4 are reverse-biased, and the transistors are non-conducting. The input signal is connected to the output through saturated transistors Q1 and Q2, and this signal is a positive half-cycle sine wave because of the in-phase condition. During the negative half-cycle of the reference signal, transistors Q1 and Q2 are switched off, and transistors Q3 and Q4 are switched on. However, the input signal will have reversed in phase, and a positive half-cycle sine wave appears at the collector of transistor Q4. Since transistors Q3 and Q4 are switched on, another positive half-cycle appears at the output. Thus, the steady-state output signal is a full-wave rectified signal with a positive DC average equal to about .636 times the peak of the sine wave.

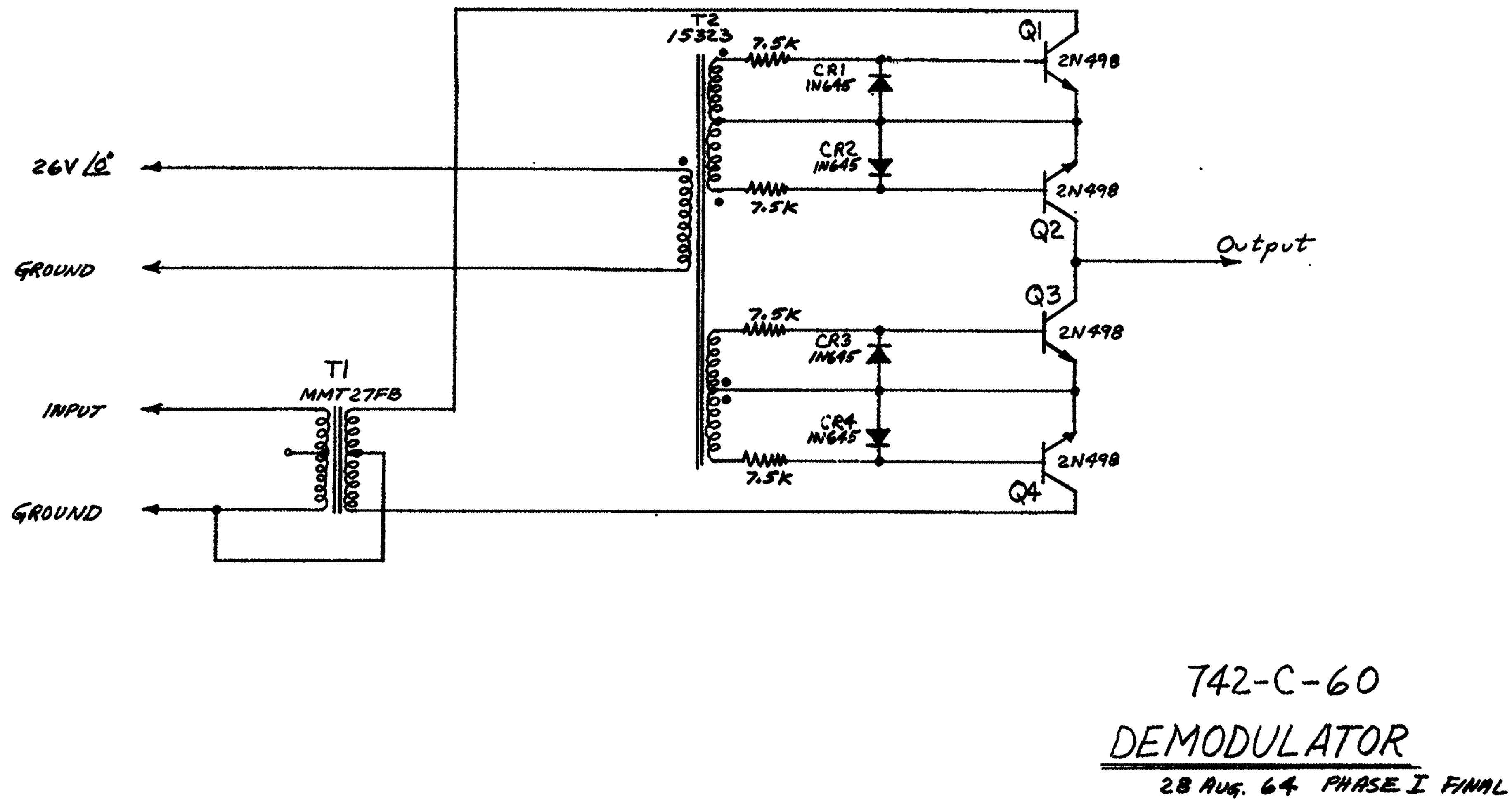


Figure I-23. Schematic, Demodulator (Sketch 742-C-60)

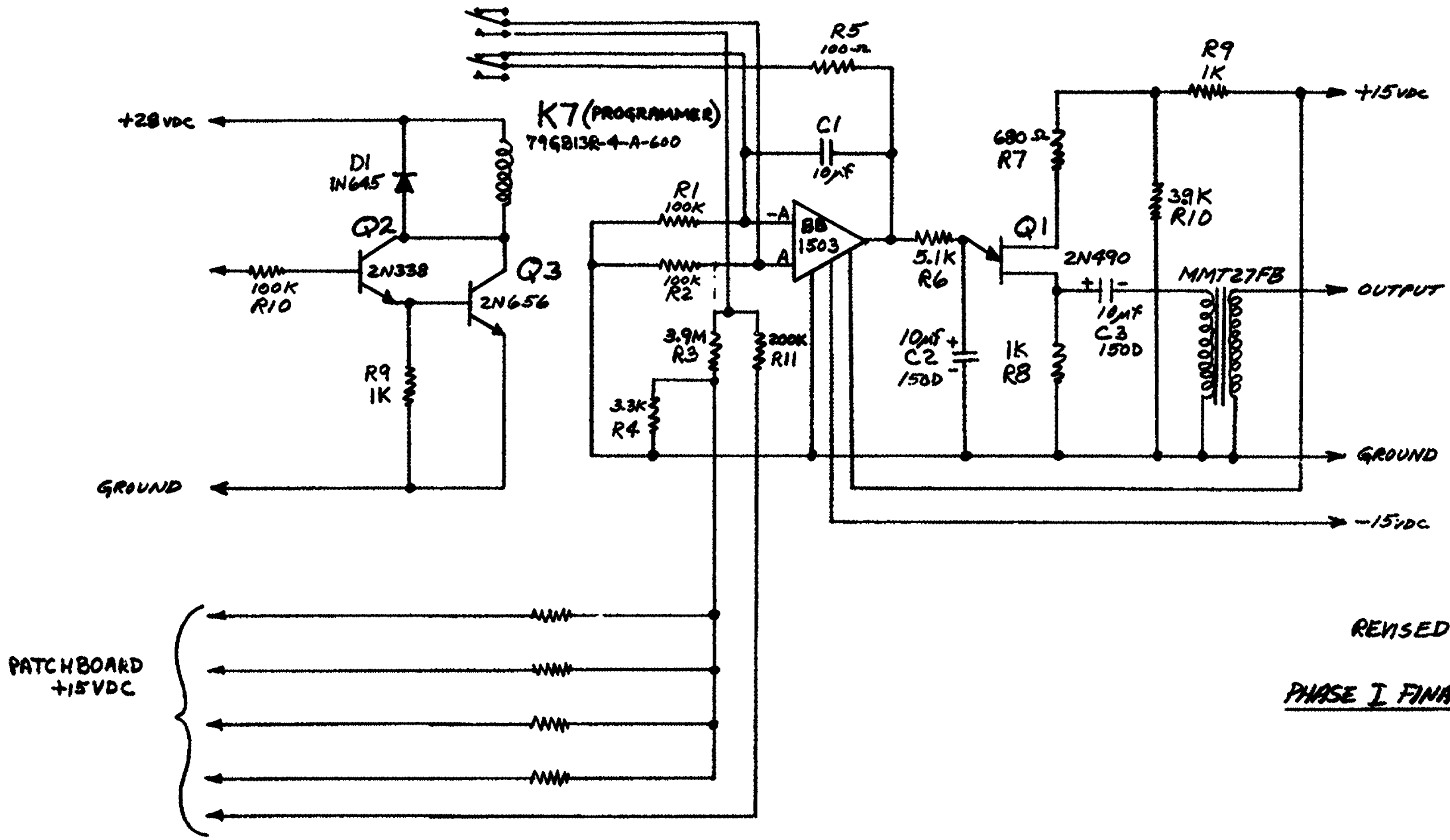
O. HOLD TIME DELAY

Selectable time delays up to 4.5 minutes are required in the FACS. A Burr-Brown operational amplifier, type 1503, is used to generate the required delays. A schematic is shown in Figure I-24.

A delay is initiated from the stepping switch contacts through selectable timing resistors. A voltage is developed across resistor R4, and a current flows through resistor R3. This same current flows through resistor R2, thereby developing a well defined voltage across resistor R2. Since the open-loop voltage gain of the amplifier is quite high (20,000), the voltage across resistor R1 must be equal to the voltage across resistor R2. Therefore, the current through resistor R1 is equal to the current through resistor R2 since the two resistors are equal in value. It is established from operational amplifier principles that essentially no current flows into the input of the amplifier. Thus, the current through capacitor C1 must be equal to the current through resistor R1. With a step voltage input, the output signal from the amplifier is in the form of a ramp, the slope of which will be directly proportional to the current through capacitor C1. The ramp signal increases until the trigger point of unijunction transistor Q1 is reached. Thus, a time delay is effected from the step input signal.

A stable time delay of 4.5 minutes can be obtained because of the very low input current drifts of the type 1503 amplifier and because capacitors can be obtained with extremely low leakage currents. Time delays within the range of 500 milliseconds to 4.5 minutes can be obtained with this circuit. For 500 millisecond delays, resistor R11 is coupled directly to the input of the amplifier.

At the completion of a time delay period, a signal is generated at the output of transistor Q1 which resets a flip-flop in the programmer. The signal from this flip-flop causes transistors Q2 and Q3 to turn off. Programmer relay K7 then de-energizes, and capacitor C1 is discharged. The relay is again energized at the next step of the stepping switch, and a new time delay is initiated.



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742-C-70

HOLD TIME DELAY

28 AUG. 64

Figure I-24. Schematic, Hold Time Delay Circuit (Sketch 742-C-70)

P. OPERATIONAL AMPLIFIER

Several mathematical operations are required in the system such as addition, scale changing, integration, etc. The Burr-Brown type 1503 operational amplifier is used to fill these various requirements. The stated specifications for the type 1503 include the following:

DC voltage stability	
Input offset	± .3 mv
Drift vs temperature	± 10 μv/°C
Drift vs supply	± 200 μv/%
Drift vs time	± 20 μv/24 hours
Bandwidth	1 mc
DC voltage gain (open loop)	20,000

The position signals and the rate signals from the gyros, after demodulation, are added by making use of the Burr-Brown operational amplifier. The DC output signal from the amplifier is the desired position plus rate signal which is then coupled to the system triggers for proper valve actuation. In-flight gain switching is readily possible with the operational amplifier. Offset caging voltages from precisely regulated sources in the console are summed into the operational amplifiers with the proper scale factor values being set by the summing resistor values at the amplifier.

These operational amplifiers are also used in the SACS control unit in the SACS valve circuits, the torque control circuits, and the level-detector circuits.

Appendix II

BREADBOARD FACS PARTS LIST

Unless otherwise indicated,

a. All resistor values are in kilohms.

b. All capacitor values are in microfarads.

c. All inductor values are in henries.

CONTENTS

A. STATIC INVERTER

Sketch 742-B-10, Figure I-1.

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	2N656		
	Q 2	2N338		
	Q 3	2N338		
	Q 4	2N338		
	Q 5	2N656		
	Q 6	2N338		
	Q 7	2N2223A		
	Q 8	2N338		
	Q 9	2N656		
	Q10	2N1486		
	Q11	2N656		
	Q12	2N1486		
	Q13	STC1726		
	Q14	2N656		
	Q15	2N1486		
	Q16	STC1726		
	Q17	2N656		
	Q18	2N338		
	Q19	2N338		
	Q20	2N338		
	Q21	2N656		
	Q22	2N1486		
	Q23	2N656		
	Q24	2N1486		
	Q25	STC1726		
	Q26	2N656		
	Q27	2N1486		
	Q28	STC1726		
	Q13A	STC1726		
	Q16A	STC1726		
	Q25A	STC1726		
	Q28A	STC1726		
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N938		9.0 V Zener
	CR 4	1N645		
	CR 5	1N827		6.2 V Zener
	CR 6	1N938		9.0 V Zener
	CR 7	1N645		
	CR 8	1N645		
	CR 9	1N645		
	CR10	1N645		
	CR11	1N645		

A. STATIC INVERTER (Continued)

Part Designation		Part No.	Value	Remarks
Diodes	CR12	1N645		
	CR13	1N645		
	CR14	SG22		
	CR15	SG22		
	CR16	SG22		
	CR17	SG22		
	CR18	1N751		5.1 V Zener
	CR19	1N645		
	CR20	1N645		
	CR21	1N645		
	CR22	1N645		
	CR23	1N757A		9.1 V Zener
Capacitors	C 1	150D106X0035R2	10	Sprague
	C 2	XG1-153A	0.015	Electron Products
	C 3	PAG2-184A	0.18	Electron Products
	C 4	XG5-824B	0.82	Electron Products
	C 5	PAG2		Electron Products
	C 6	150D105X0035A2	1	Sprague
	C 7	150D106X0035A2	10	Sprague
	C 8	150D476X0035S2	47	Sprague
	C 9	150D476X0035S2	47	Sprague
	C10	150D106X0035R2	10	Sprague
	C11	150D476X0035S2	47	Sprague
	C12	150D106X0035R2	10	Sprague
	C13	150D104X0035A2	0.1	Sprague
	C14	150D104X0035A2	0.1	Sprague
	C15	150D476X0035S2	47	Sprague
	C16	150D476X0035S2	47	Sprague
	C17	150D104X0035A2	0.1	Sprague
	C18	150D476X0035S2	47	Sprague
	C19	150D476X0035S2	47	Sprague
	C20	150D106X0035R2	10	Sprague
	C21	150D474X0035A2	0.47	Sprague
	C22	150D106X0035R2	10	Sprague
	C23	TES300-50NX-P-1	300	International Elec Inc
	C24	CL37BJ300MN-3	30	International Elec Inc
	C25	CL37BJ100MN-3	10	International Elec Inc
Transformers	T 1	14879		Hadley
	T 2	14880		Hadley
	T 3	14714		Hadley
	T 4	14879		Hadley
	T 5	14880		Hadley
	T 6	14714		Hadley

A. STATIC INVERTER (Continued)

Part Designation	Part No.	Value	Remarks
Transformers T 3A	14714		Hadley
T 6A	14714		Hadley
Inductors L 1	MQA-12	1	U.T.C.
Resistors R 1	RC07GF103J	10	
R 2	RN60B2371F	2.37	
R 3	RN65E5110F	511Ω	
R 4	3010P-1-102	1	Bourns
R 5	RN60B3322F	33.2	
R 6	RN60B1002F	10	
R 7	RN60B1001F	1	
R 8	RN60B4751F	4.75	
R 9	RC07GF472J	4.7	
R10	RN60B2001F	2	
R11	RN60B4321F	4.32	
R12	RC07GF133J	13	
R13	3010P-1-103	10	Bourns
R14	RN65E5111F	5.11	
R15	RC07GF102J	1	
R17	RC07GF510J	51Ω	
R18	RN60B5622F	56.2	
R19	RN60B6191F	6.19	
R20	RN60B1002F	10	
R21	RN60B2001F	2	
R22	RN60B2212F	22.1	
R23	RC42GF331J	330Ω	
R24	RC20GF332J	3.3	
R25	RC07GF102J	1	
R26	RC07GF101J	100Ω	
R27	RC07GF102J	1	
R28	RC07GF101J	100Ω	
R29	RN60B7500F	750Ω	
R31	RC07GF223J	22	
R32	RC07GF472J	4.7	
R33	RC07GF103J	10	
R34	RC07GF223J	22	
R35	RC07GF104J	100	
R36	RC07GF202J	2	
R37	RC07GF104J	100	
R38	RN65E7501F	7.5	
R39	3010P-1-102	1	Bourns
R40	3010P-1-502	5	Bourns
R41	RC07GF683J	68	
R42	RC07GF104J	100	

A. <u>STATIC INVERTER</u> (Continued)

Part Designation		Part No.	Value	Remarks
<u>Resistors</u>	R43	RN60B5112F	51.1	
	R44	RC07GF512J	5.1	
	R45	RN60B7501F	7.5	
	R46	RC07GF102J	1	
	R47	RN60B4321F	4.32	
	R48	RC07GF103J	10	
	R49	3010P-1-102	10	Bourns
	R50	RC42GF331J	330Ω	
	R51	RC20GF332J	3.3	
	R52	RC07GF102J	1	
	R53	RC07GF101J	100Ω	
	R54	RC07GF102J	1	
	R55	RC07GF101J	100Ω	
	R56	RN60B7500F	750Ω	
	R59	RN65E1001F	1	
	R60	RN65E2431F	2.43	
	R61	RC07GF205J	2 Meg	
	R62	RN65E1501F	1.5	

B. DC POWER SUPPLY

Sketch 742-B-20, Figure I-2.

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	2N1486		
	Q 2	2N656		
	Q 3	2N2223A		
	Q 4	2N2223A		
	Q 5	2N656		
	Q 1A	2N1486		
	Q 2A	2N656		
	Q 3A	2N2223A		
	Q 4A	2N2223A		
	Q 5A	2N656		
Diodes	CR 1	1N538		
	CR 2	1N538		
	CR 3	1N827		6.2 V Zener
	CR 3A	1N827		6.2 V Zener
Resistors	R 1	RC07GF103J	10	
	R 2	RC07GF332J	3.3	
	R 3	RN65E8251F	8.25	
	R 4	RN60B1301F	1.3	
	R 5	RN60B1502F	15	
	R 6	RN60B3921F	3.92	
	R 7	RN60B1502F	15	
	R 8	RN60B8251F	8.25	
	R 9	3010P-1-202	2	Bourns
	R10	RN65E5761F	5.76	
	R11	5%-TYPE AS-2-2W	0.47Ω	IRC
	R 1A	RC07GF103J	10	
	R 2A	RC07GF332J	3.3	
	R 3A	RN65E8251F	8.25	
	R 4A	RN60B1301F	1.3	
	R 5A	RN60B1502F	15	
	R 6A	RN60B3921F	3.92	
	R 7A	RN60B1502F	15	
	R 8A	RN60B8251F	8.25	
	R 9A	3010P-1-202	2	Bourns
	R10A	RN65E5761F	5.76	
	R11A	5%-TYPE AS-2-2W	0.47Ω	IRC
Inductors	L 1	15239	0.1	Hadley

B. DC POWER SUPPLY (Continued)

Part Designation		Part No.	Value	Remarks
Transformers	T 1	15277		Hadley
Capacitors	C 1	150D476X0035S2	47	Sprague
	C 2	MG 1-224	0.22	Electron Products
	C 3	150D476X0035S2	47	Sprague
	C 2A	MC 1-224	0.22	Electron Products
	C 3A	150D476X0035S2	47	Sprague

C. PROGRAMMER

Sketch 742-B-30, Figure I-3.

Part Designation		Part No.	Value	Remarks
Relays	K 1	79GB13R-4-A-600		Electronic Specialty
	K 2	93GB13-4-A-480		Electronic Specialty
	K 3	103HB16-4-A-250		Electronic Specialty
	K 4	79GB13R-4-A-600		Electronic Specialty
	K 5	93GB13-4-A-480		Electronic Specialty
	K 6	103HB16-4-A-250		Electronic Specialty
	K 7	79GB13R-4-A-600		Electronic Specialty
	K 8	103HB16-4-A-250		Electronic Specialty
Transformers	T 1	MMT18-FB		Microtran
	T 2	C 683		Electro Winders
	T 3	C 683		Electro Winders
	T 4	MMT27FB		Microtran
Switch	S 1	S10019-023		Ledex
Transistors	Q 1	2N490		Unijunction
	Q 2	2N1597		SCR
	Q 3	2N656		
	Q 4	2N338		
	Q 5	2N656		
	Q 6	2N338		
	Q 7	2N338		
	Q 8	2N338		
	Q 9	2N490		Unijunction
	Q10	2N338		
	Q11	2N338		
	Q12	2N656		
	Q13	2N656		
	Q14	2N1486		
	Q15	2N338		
	Q16	2N338		
	Q17	2N338		
	Q18	2N338		
	Q19	2N338		
	Q20	2N1486		
	Q21	2N2223A		
	Q22	2N338		
	Q23	2N338		
	Q24	2N656		

C. PROGRAMMER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RN65E9091F	9.09	
	R 2	RN65E1691F	1.69	
	R 3	RN65E9763F	976	
	R 4	RN65E2002F	20	
	R 5	RN65E5231F	5.23	
	R 6	RN65E5231F	5.23	
	R 7	RN65E5231F	5.23	
	R 8	RN65E3572F	35.7	
	R 9	RN65E9091F	9.09	
	R10	RN65E1691F	1.69	
	R11	RN65E9763F	976	
	R12	RN60B8662F	86.6	
	R13	RN60B2553F	255	
	R14	RN60B5623F	562	
	R15	RN65D1504F	1.5 Meg	
	R16	RN60B9531F	9.53	
	R17	RN65E2201F	2.2	
	R18	RN65E6650F	665Ω	
	R19	RN65E7501F	7.5	
	R20	RN65E3241F	3.24	
	R21	RN65E1004F	1 Meg	
	R22	RN65E5622F	56.2	
	R23	RN65E1004F	1 Meg	
	R24	RN65E5622F	56.2	
	R25	RN65E1004F	1 Meg	
	R26	RN60B4533K	453	
	R27	RC07GF100J	10Ω	
	R28	RC07GF104J	100	
	R29	RC07GF102J	1	
	R30	RC07GF-J		Selected
	R31	RC07GF-J		Selected
	R32	RC07GF-J		Selected
	R33	RC07GF-J		Selected
	R34	RN65E5111F	5.11	
	R35	RN65E5111F	5.11	
	R36	RC07GF104J	100	
	R37	RC07GF104J	100	
	R38	RC07GF332J	3.3	
	R39	RC07GF392J	3.9 Meg	
	R40	RC07GF101J	100Ω	
	R41	RC07GF512J	5.1	
	R42	RC07GF102J	1	
	R43	RC07GF681J	680Ω	
	R44	RC07GF102J	1	
	R45	55-9-143-203	20	Spectrol

C. <u>PROGRAMMER</u> (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R46	55-9-143-203	20	Spectrol
	R47	55-9-143-203	20	Spectrol
	R48	55-9-143-203	20	Spectrol
	R49	55-9-143-203	20	Spectrol
	R50	55-9-143-203	20	Spectrol
	R51	55-9-143-203	20	Spectrol
	R52	55-9-143-203	20	Spectrol
	R53	55-9-143-203	20	Spectrol
	R54	55-9-143-203	20	Spectrol
	R55	RC07GF392J	3.9	
	R56	3010P-1-102	1	Bourns
	R57	RC07GF223J	22	
	R58	RC07GF302J	3	
	R59	RN60B4990F	499Ω	1/8 W
	R60	RN60B4990F	499Ω	1/8 W
	R61	RN60B4990F	499Ω	1/8 W
	R62	RN60B4990F	499Ω	1/8 W
	R63	RN60B4990F	499Ω	1/8 W
	R64	RN60B4990F	499Ω	1/8 W
	R65	RN60B4990F	499Ω	1/8 W
	R66	RN60B4990F	499Ω	1/8 W
	R67	RN60B4990F	499Ω	1/8 W
	R63	RN60B4990F	499Ω	1/8 W
	R69	RN60B4990F	499Ω	1/8 W
	R70	RC07GF302J	3	
	R71	RC07GF103J	10	
	R72	RC07GF103J	10	
	R73	RC07GF103J	10	
	R74	RC07GF104J	100	
	R75	RC07GF391J	390Ω	
	R76	RC07GF681J	680Ω	
	R77	RC07GF681J	680Ω	
	R78	RC07GF103J	10	
	R79	RC07GF153J	15	
	R80	RC07GF752J	7.5	
	R81	RC07GF222J	2.2	
	R82	RC07GF223J	22	
	R83	RC07GF223J	22	
	R84	RC07GF103J	10	
	R85	RC07GF223J	22	
	R86	RC07GF223J	22	
	R87	RC07GF103J	10	
	R88	RC07GF333J	33	
	R89	RC07GF103J	10	
	R90	RC07GF103J	10	
	R91	RC07GF753J	75	

C. PROGRAMMER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R92	RC07GF753J	75	
	R93	RC07GF103J	10	
	R94	RC07GF103J	10	
	R95	RC07GF333J	33	
	R96	RC07GF223J	22	
	R97	RC07GF103J	10	
	R98	RC07GF333J	33	
	R99	RC07GF512J	5.1	
	R100	RC07GF752J	7.5	
	R101	RC07GF103J	10	
	R102	RC07GF752J	7.5	
	R103	RC07GF104J	100	
	R104	RC07GF103J	10	
	R105	RC07GF103J	10	
	R106	RC07GF153J	15	
	R107	RC07GF203J	20	
	R108	RC20GF332J	3.3	
	R109	RC07GF103J	10	
	R110	RC07GF103J	10	
	R111	RC07GF753J	75	
	R112	RC07GF753J	75	
	R113	RC07GF103J	10	
	R114	RC07GF103J	10	
	R115	RC07GF103J	10	
	R116	RC07GF103J	10	
	R117	RC07GF753J	75	
	R118	RC07GF753J	75	
	R119	RC07GF103J	10	
	R120	RC07GF103J	10	
	R121	RC07GF273J	27	
	R122	RC07GF103J	10	
	R123	RN60B1502F	15	
	R124	RN65E7501F	7.5	
	R125	RN60B1502F	15	
	R126	RN65E7501F	7.5	
	R127	RC07GF154J	150	
	R128	RC07GF273J	27	
	R129	RC07GF272J	2.7	
	R130	RC07GF272J	2.7	
	R131	RC07GF102J	1	
	R132	RC07GF333J	33	
	R133	RC07GF153J	15	
	R134	RC07GF103J	10	
	R135	RN65E1001F	1	

C. PROGRAMMER (Continued)

Part Designation		Part No.	Value	Remarks
Capacitors	C 1	150D106X0035R2	10	Sprague
	C 2	150D476X0035S2	47	Sprague
	C 3	2DE1-104	.1	Electron Products
	C 4	2DE1-104	.1	Electron Products
	C 5	150D105X0035A2	1	Sprague
	C 6	150D105X0035A2	1	Sprague
	C 7	2DE1-273	.027	Electron Products
	C 8	2DE1-104	.1	Electron Products
	C 9	EP34313	5	Electron Products
	C10	150D476X0035S2	47	Sprague
	C11	150D476X0035S2	47	Sprague
	C12	150D106X0035R2	10	Sprague
	C13	150D106X0035R2	10	Sprague
	C14	109D107C2025T2	100	Sprague
	C15	150D106X0035R2	10	Sprague
	C16	150D105X0035A2	1	Sprague
	C17	150D105X0035A2	1	Sprague
	C18	150D155X0020A2	1.5	Sprague
	C19	150D476X0035S2	47	Sprague
	C20	150D105X0035A2	1	Sprague
	C21	150D105X0035A2	1	Sprague
	C22	150D105X0035A2	1	Sprague
	C23	2D1-106D	10	Electron Products
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N645		
	CR 4	1N645		
	CR 5	1N645		
	CR 6	1N645		
	CR 7	1N645		
	CR 8	1N645		
	CR 9	1N645		
	CR10	1N645		
	CR11	1N645		
	CR12	1N645		
	CR13	1N645		
	CR14	1N645		
	CR15	1N645		
	CR16	1N645		
	CR17	1N645		
	CR18	1N645		
	CR19	1N645		
	CR20	1N645		
	CR21	1N457		

C. <u>PROGRAMMER</u> (Continued)

Part Designation		Part No.	Value	Remarks
Diodes	CR22	1N457		
	CR23	1N457		
	CR24	1N645		
	CR25	1N645		
	CR26	1N645		
	CR27	1N645		
	CR28	1N645		
	CR29	1N645		
	CR30	1N645		
	CR31	1N645		
	CR32	1N645		
	CR33	1N645		
	CR34	1N645		
	CR35	1N645		
	CR36	1N752A		5.6 V Zener
	CR37	1N645		
	CR38	1N645		
	CR39	1N645		
	CR40	1N645		
	CR41	1N645		
	CR42	1N746A		3.3 V Zener
	CR43	1N645		
	CR44	1N645		
	CR45	1N645		
	CR46	1N645		
	CR47	1N645		
	CR48	1N645		
	CR49	1N645		
	CR50	1N645		
	CR51	1N645		
	CR52	1N752A		5.6 V Zener
	CR53	1N645		
	CR54	1N645		
	CR55	1N645		
	CR56	1N645		
	CR57	1N752A		5.6 V Zener
	CR58	1N645		
	CR59	1N645		
	CR60	1N645		
	CR61	1N645		
	CR62	1N645		
	CR63	1N752A		5.6 V Zener
	CR64	1N538		
	CR65	1N645		
	CR66	1N752A		5.6 V Zener
	CR67	1N645		

D. IACS CONTROL ELECTRONICS

Sketch 742-B-40, Figure I-5.

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC07GF104J	100	
	R 2	RC07GF104J	100	
	R 3	RC07GF203J	20	
	R 4	RC07GF203J	20	
	R 5	RC07GF155J	1.5 Meg	
	R 6	RC07GF155J	1.5 Meg	
	R 7	RC07GF512J	5.1	
	R 8	RC07GF512J	5.1	
	R 9	RC07GF512J	5.1	
	R10	RC07GF512J	5.1	
	R11	RC07GF103J	10	
	R12	RC07GF103J	10	
	R13	RC07GF103J	10	
	R14	RC07GF103J	10	
	R15	RC07GF183J	18	
	R16	RC07GF273J	27	
	R17	RC07GF183J	18	
	R18	RC07GF273J	27	
	R19	RC07GF183J	18	
	R20	RC07GF273J	27	
	R21	RC07GF332J	3.3	
	R22	RC07GF332J	3.3	
	R23	RC07GF332J	3.3	
	R24	RC07GF103J	10	
	R25	RC07GF103J	10	
	R26	RC07GF103J	10	
	R27	RC07GF103J	10	
	R28	RC07GF103J	10	
	R29	RC07GF154J	150	
	R30	RC07GF103J	10	
	R31	RC07GF103J	10	
	R32	RC07GF154J	150	
	R33	RC07GF563J	56	
	R34	RC07GF563J	56	
	R35	RC07GF103J	10	
	R36	RC07GF103J	10	
	R37	RC07GF103J	10	
	R38	RC07GF103J	10	
	R39	RC07GF103J	10	
	R40	RC07GF103J	10	
	R41	RC07GF273J	27	
	R42	RC07GF154J	150	

D. IACS CONTROL ELECTRONICS (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R43	RC07GF434J	430	
	R44	RC07GF683J	68	
	R45	RC07GF683J	68	
	R46	RC07GF184J	180	
	R47	RC07GF434J	430	
	R48	RC07GF204J	200	
	R49	RC07GF434J	430	
	R50	RC07GF204J	200	
	R51	RC07GF434J	430	
	R52	RC07GF305J	3 Meg	
	R53	RC07GF822J	8.2	
	R54	RC07GF821J	820Ω	
	R55	RC07GF821J	820Ω	
	R56	RC07GF822J	8.2	
	R57	RC07GF305J	3 Meg	
	R58	RC07GF305J	3 Meg	
	R59	RC07GF305J	3 Meg	
	R60	RC07GF822J	8.2	
	R61	RC07GF821J	820Ω	
	R62	RC07GF822J	8.2	
	R63	RC07GF821J	820Ω	
	R64	RC07GF822J	8.2	
	R65	RC07GF821J	820Ω	
	R66	RC07GF822J	8.2	
	R67	RC07GF821J	820Ω	
	R68	RC07GF822J	8.2	
	R69	RC07GF821J	820Ω	
	R70	RC07GF822J	8.2	
	R71	RC07GF821J	820Ω	
	R72	RC07GF103J	10	
	R73	RC07GF332J	3.3	
	R74	RC42GF821J	820Ω	
	R75	RC07GF272J	2.7	
	R76	RC07GF272J	2.7	
	R77	RC07GF752J	7.5	
	R78	RC07GF752J	7.5	
	R79	RC07GF752J	7.5	
	R80	RC07GF752J	7.5	
	R81	RC07GF752J	7.5	
	R82	RC07GF752J	7.5	
	R83	RC07GF752J	7.5	
	R84	RC07GF752J	7.5	
	R85	RC07GF752J	7.5	
	R86	RC07GF752J	7.5	
	R87	RC07GF752J	7.5	

D. IACS CONTROL ELECTRONICS (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R88	RC07GF752J	7.5	
	R89	RC07GF752J	7.5	
	R90	RC07GF752J	7.5	
	R91	RC07GF752J	7.5	
	R92	RC07GF752J	7.5	
	R93	RC07GF752J	7.5	
	R94	RC07GF752J	7.5	
	R95	RC07GF752J	7.5	
	R96	RC07GF752J	7.5	
	R97	RC07GF752J	7.5	
	R98	RC07GF752J	7.5	
	R99	RC07GF752J	7.5	
	R100	RC07GF752J	7.5	
	R101	RC07GF752J	7.5	
	R102	RC07GF752J	7.5	
	R103	RC07GF752J	7.5	
	R104	RC07GF752J	7.5	
	R105	RC07GF512J	5.1	
	R106	RC07GF512J	5.1	
Capacitors	C 1	2DE1-472	.047	Electron Products
	C 2	2DE1-472	.047	Electron Products
	C 3	150D105X0035A2	1.0	Sprague
	C 4	150D105X0035A2	1.0	Sprague
	C 5	150D105X0035A2	1.0	Sprague
	C 6	150D226X0015B2	22	Sprague
	C 7	150D226X0015B2	22	Sprague
	C 8	150D226X0015B2	22	Sprague
	C 9	2DE1-105	1.0	Electron Products
	C10	2DE1-105	1.0	Electron Products
	C11	2DE1-105	1.0	Electron Products
	C12	2DE1-105	1.0	Electron Products
	C13	2DE1-105	1.0	Electron Products
	C14	2DE1-105	1.0	Electron Products
	C15	2DE1-105	1.0	Electron Products
	C16	2DE1-105	1.0	Electron Products
	C17	2DE1-105	1.0	Electron Products
	C18	2DE1-105	1.0	Electron Products
	C19	2DE1-105	1.0	Electron Products
	C20	2DE1-105	1.0	Electron Products
	C21	2DE1-105	1.0	Electron Products
	C22	2DE1-682	0.0068	Electron Products
	C23	2DE1-682	0.0068	Electron Products
	C24	2DE1-682	0.0068	Electron Products
	C25	2DE1-682	0.0068	Electron Products

D. IACS CONTROL ELECTRONICS (Continued)

Part Designation		Part No.	Value	Remarks
Capacitors	C26	150D105X0035A2	1.0	Sprague
	C27	Disc	.22	
	C28	Disc	.22	
	C29	Disc	.22	
	C30	Disc	.22	
Transistors	Q 1	2N338		
	Q 2	2N338		
	Q 3	2N338		
	Q 4	2N338		
	Q 5	2N338		
	Q 6	2N656		
	Q 7	2N656		
	Q 8	2N338		
	Q 9	2N338		
	Q10	2N656		
	Q11	2N656		
	Q12	2N656		
	Q13	2N656		
	Q14	2N656		
	Q15	2N1486		
	Q16	2N656		
	Q17	2N1486		
	Q18	2N656		
	Q19	2N1486		
	Q20	2N656		
	Q21	2N1486		
	Q22	2N656		
	Q23	2N1486		
	Q24	2N656		
	Q25	2N1486		
Diodes	CR 1	1N457		
	CR 2	1N457		
	CR 3	1N457		
	CR 4	1N457		
	CR 5	1N645		
	CR 6	1N645		
	CR 7	1N645		
	CR 8	1N457		
	CR 9	1N457		
	CR10	1N457		
	CR11	1N457		
	CR12	1N457		
	CR13	1N457		
	CR14	1N457		

D. IACS CONTROL ELECTRONICS (Continued)

Part Designation		Part No.	Value	Remarks
Diodes	CR15	1N457		
	CR16	1N645		
	CR17	1N645		
	CR18	2N2323		SCR
	CR19	1N645		
	CR20	1N645		
	CR21	1N1124A		
	CR22	1N645		
	CR23	1N645		
	CR24	1N645		
	CR25	1N645		
	CR26	1N645		
	CR27	1N1124A		
	CR28	1N751		5.1 V Zener
	CR29	1N751		5.1 V Zener
	CR30	1N751		5.1 V Zener
	CR31	1N751		5.1 V Zener
Transformers	T 1	MMT-27-FB		Microtron
	T 2	MMT-27-FB		Microtron
	T 3	MMT-27-FB		Microtron
	T 4	MMT-27-FB		Microtron
	T 5	MMT-27-FB		Microtron
	T 6	MMT-27-FB		Microtron
	T 7	MMT-27-FB		Microtron
	T 8	15323		Hadley
	T 9	15323		Hadley
	T10	15323		Hadley
	T11	15323		Hadley
	T12	15323		Hadley
	T13	15323		Hadley
	T14	15323		Hadley
Relays	K 1	79GB13R-4-A-600		Electronic Specialty
	K 2	79GB13R-4-A-600		Electronic Specialty
	K 3	79GB13R-4-A-600		Electronic Specialty
	K 4	936B13-4-A480		Electronic Specialty
	K 5	936B13-4-A480		Electronic Specialty
	K 6	936B13-4-A480		Electronic Specialty
	K 7	936B13-4-A480		Electronic Specialty
	K 8	79GB13R-4-A-600		Electronic Specialty
	K 9	79GB13R-4-A-600		Electronic Specialty
Amplifiers	A 1	BB 1503		Burr Brown
	A 2	BB 1503		Burr Brown
	A 3	BB 1503		Burr Brown
	A 4	BB 1503		Burr Brown

D. IACS CONTROL ELECTRONICS (Continued)

ABSOLUTE VALUE CKT - 3 MODULES: Z1, Z2 & Z3
Figure I-21.

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC07GF104J	100	
	R 2	RC07GF223J	22	
	R 3	RC07GF101J	100Ω	
Capacitor	C 1	150D157X0015S2	150	Sprague
Transistors	Q 1	2N1132		
	Q 2	2N338		
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N645		

D. IACS CONTROL ELECTRONICS (Continued)

HALF TRIGGER - 3 MODULES: Z4, Z5 & Z6
Figure I-20.

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC07GF513J	51	
	R 2	RN60B1502F	15	
	R 3	RN60B1502F	15	
	R 4	RN65E1002F	10	
	R 5	3010P-1-502	5	Bourns
	R 6	RN65E1002F	10	
	R 7	RC07GF154J	150	
	R 8	RC07GF272J	2.7	
	R 9	RC07GF273J	27	
	R10	RC07GF102J	1	
	R11	RC07GF272J	2.7	
	R12	RC07GF333J	33	
	R13	RC07GF153J	15	
	R14	RC07GF103J	10	
Transistors	Q 1	2N2223A		
	Q 2	2N338		
	Q 3	2N338		
	Q 4	2N338		
Diodes	CR 1	1N645		
	CR 2	1N752A		5.6 V Zener
	CR 3	1N645		

D. IACS CONTROL ELECTRONICS (Continued)

DEMODULATOR - 7 MODULES: Z7, Z8, Z9, Z10, Z11, Z12 & Z13
Figure I-23.

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	2N498		
	Q 2	2N498		
	Q 3	2N498		
	Q 4	2N498		
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N645		
	CR 4	1N645		
Resistors	R 1	RC07GF223J	22	
	R 2	RC07GF752J	7.5	
	R 3	RC07GF752J	7.5	
	R 4	RC07GF752J	7.5	
	R 5	RC07GF752J	7.5	

D. IACS CONTROL ELECTRONICS (Continued)

FULL TRIGGER - 4 MODULES: (Z14 & Z15), (Z16 & Z17), (Z18 & Z19), (Z20 & Z21)
Figure I-19.

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	½2N2223A		
	Q 2	½2N2223A		
	Q 3	½2N2223A		
	Q 4	½2N2223A		
	Q 5	2N338		
	Q 6	2N338		
	Q 7	2N338		
	Q 8	2N338		
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N752A		5.6 V Zener
	CR 4	1N752A		5.6 V Zener
	CR 5	1N645		
	CR 6	1N645		
Resistors	R 1	RC07GF202J	2	
	R 2	RC07GF431J	430Ω	
	R 3	RC07GF431J	430Ω	
	R 4	RN60B1502F	15	
	R 5	RN60B1502F	15	
	R 6	RN65E1002F	10	
	R 7	3010P-1-502	5	Bourns
	R 8	RN65E1002F	10	
	R 9	RC07GF154J	150	
	R10	RC07GF272J	2.7	
	R11	RC07GF273J	27	
	R12	RC07GF102J	1	
	R13	RC07GF272J	2.7	
	R14	RC07GF333J	33	
	R15	RC07GF153J	15	
	R16	RC07GF202J	2	
	R17	RC07GF431J	430Ω	
	R18	RC07GF431J	430Ω	
	R19	RN60B1502F	15	
	R20	RN60B1502F	15	
	R21	RN65E1002F	10	
	R22	3010P-1-502	5	Bourns
	R23	RN65E1002F	10	
	R24	RC07GF154J	150	
	R25	RC07GF272J	2.7	

D. IACS CONTROL ELECTRONICS (Continued)

FULL TRIGGER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R26	RC07GF273J	27	
	R27	RC07GF102J	1	
	R28	RC07GF272J	2.7	
	R29	RC07GF333J	33	
	R30	RC07GF153J	15	

E. SACS CONTROL ELECTRONICS

Sketch 742-B-50, Figure 1-7.

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC07GF104J	100	
	R 2	RC07GF104J	100	
	R 3	RC07GF135J	1.3 Meg	
	R 4	RC07GF135J	1.3 Meg	
	R 5	RC07GF103J	10	
	R 6	RC07GF512J	5.1	
	R 7	RC07GF103J	10	
	R 8	RC07GF512J	5.1	
	R 9	RC07GF103J	10	
	R10	RC07GF512J	5.1	
	R11	RC07GF102J	1	
	R12	RC07GF103J	10	
	R13	RC07GF512J	5.1	
	R14	RC07GF102J	1	
	R15	RC07GF133J	13	
	R16	RC07GF224J	220	
	R17	RC07GF275J	2.7 Meg	
	R18	RC07GF154J	150	
	R19	RC07GF203J	20	
	R20	RC07GF203J	20	
	R21	RC07GF154J	150	
	R22	RC07GF275J	2.7 Meg	
	R23	RC07GF224J	220	
	R24	RC07GF133J	13	
	R25	RC07GF223J	22	
	R26	RC07GF223J	22	
	R27	RC07GF205J	2 Meg	
	R28	RC07GF205J	2 Meg	
	R29	RC07GF205J	2 Meg	
	R30	RC07GF205J	2 Meg	
	R31	RC07GF103J	10	
	R32	RC07GF202J	2	
	R33	RC07GF822J	8.2	
	R34	RC07GF821J	820Ω	
	R35	RC07GF821J	820Ω	
	R36	RC07GF822J	8.2	
	R37	RC07GF202J	2	
	R38	RC07GF103J	10	
	R39	RC07GF103J	10	
	R40	RC07GF202J	2K	
	R41	RC07GF822J	8.2	
	R42	RC07GF821J	820Ω	
	R43	RC07GF821J	820Ω	

E. SACS CONTROL ELECTRONICS (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R44	RC07GF822J	8.2	
	R45	RC07GF202J	2	
	R46	RC07GF103J	10	
	R47	RC07GF102J	1	
	R48	RC07GF102J	1	
	R49	RC07GF243J	24	
	R50	RC07GF102J	1	
	R51	RC07GF243J	24	
	R52	RC07GF243J	24	
	R53	RC07GF223J	22	
	R54	RC07GF223J	22	
	R55	RC07GF223J	22	
	R56	RC07GF223J	22	
	R57	RC07GF223J	22	
	R58	RC07GF223J	22	
	R59	RC07GF223J	22	
	R60	RC07GF103J	10	
	R61	RC07GF103J	10	
	R62	RC07GF513J	51	
	R63	RC07GF223J	22	
	R64	RC07GF103J	10	
	R65	RC07GF103J	10	
	R66	RC07GF753J	75	
	R67	RC07GF102J	1	
	R68	RC07GF243J	24	
	R69	RC07GF334J	330	
	R70	RC07GF124J	120	
	R71	RC07GF513J	51	
	R72	RC07GF223J	22	
	R73	RC07GF103J	10	
Capacitors	C 1	150D106X0035R2	10	Sprague
	C 2	150D106X0035R2	10	Sprague
	C 3	2DE1-205	2	Electron Products
	C 4	2DE1-564	.56	Electron Products
	C 5	2DE1-564	.56	Electron Products
	C 6	2DE1-205	2	Electron Products
	C 7	2DE1-153	.015	Electron Products
	C 9	150D105X0035A2	1	Sprague
	C10	150D105X0035A2	-	Sprague
	C12	2DE1-153	.015	Electron Products
	C13	109D107C2010F2	100	Sprague
	C14	109D107C2010F2	100	Sprague
	C15	109D107C2010F2	100	Sprague
	C16	150D104X0035A2	.1	Sprague
	C17	150D104X0035A2	.1	Sprague
	C18	109D476X0010C2	47	Sprague
	C19	150D105X0035A2	1	Sprague

E. SAC3 CONTROL ELECTRONICS (Continued)

Part Designation		Part No.	Value	Remarks
Diodes	CR 1	1N457		
	CR 2	1N457		
	CR 3	1N457		
	CR 4	1N457		
	CR 5	1N457		
	CR 6	1N457		
	CR 7	1N457		
	CR 8	1N457		
	CR 9	1N457		
	CR10	1N457		
	CR11	1N457		
	CR12	1N457		
	CR13	1N457		
	CR14	1N457		
	CR15	1N645		
	CR16	1N645		
	CR17	1N645		
	CR18	1N645		
	CR19	1N645		
	CR20	1N645		
	CR21	1N645		
	CR22	1N752A		5.6 V Zener
	CR23	1N752A		5.6 V Zener
	CR24	1N752A		5.6 V Zener
	CR25	1N645		
	CR26	1N645		
	CR27	1N645		
	CR28	1N645		
	CR29	1N752A		5.6 V Zener
	CR30	1N645		
	CR31	1N645		
	CR32	1N645		
	CR33	1N645		
	CR34	1N645		
	CR35	1N645		
	CR36	1N645		
	CR37	1N645		
	CR38	1N645		
	CR39	1N645		
	CR40	1N645		
	CR41	1N645		
	CR42	1N645		
	CR43	1N645		
	CR44	1N645		
	CR45	1N645		
	CR46	1N645		

E. SACS CONTROL ELECTRONICS (Continued)

Part Designation	Part No.	Value	Remarks
Diodes CR47	1N751		5.1 V Zener
CR48	1N751		5.1 V Zener
CR49	1N751		5.1 V Zener
CR50	1N751		5.1 V Zener
Transistors Q 1	2N338		
Q 2	2N338		
Q 3	2N338		
Q 4	2N338		
Q 5	2N656		
Q 6	2N656		
Q 7	2N656		
Q 8	2N656		
Q 9	2N338		
Q10	2N338		
Q11	2N656		
Q12	2N338		
Q13	2N656		
Q14	2N656		
Q15	2N1486		
Q16	2N338		
Q17	2N656		
Q18	2N338		
Q19	2N656		
Relays K 1	79GB13R-4-A-600		Electronic Specialty
K 2	93GB13-4-A-480		Electronic Specialty
K 3	93GB13-4-A-480		Electronic Specialty
K 4	93GB13-4-A-480		Electronic Specialty
K 5	79GB13R-4-A-600		Electronic Specialty
K 6	93GB13-4-A-480		Electronic Specialty
K 7	93GB13-4-A-480		Electronic Specialty
K 8	93GB13-4-A-480		Electronic Specialty
K 9	93GB13-4-A-480		Electronic Specialty
K10	93GB13-4-A-480		Electronic Specialty
Amplifiers A 1	1503		Burr Brown
A 2	1503		Burr Brown
A 3	1503		Burr Brown
A 4	1503		Burr Brown
A 5	1503		Burr Brown
A 6	1503		Burr Brown

E. SACS CONTROL ELECTRONICS (Continued)

HALF TRIGGER - 2 MODULES: Z1 & Z2
Figure I-20.

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC07GF513J	51	
	R 2	RN60B1502F	15	
	R 3	RN60B1502F	15	
	R 4	RN65E1002F	10	
	R 5	3010P-1-502	5	Bourns
	R 6	RN65E1002F	10	
	R 7	RC07GF154J	150	
	R 8	RC07GF272J	2.7	
	R 9	RC07GF273J	27	
	R10	RC07GF102J	1	
	R11	RC07GF272J	2.7	
	R12	RC07GF333J	33	
	R13	RC07GF153J	15	
	R14	RC07GF103J	10	
Transistors	Q 1	2N2223A		
	Q 2	2N338		
	Q 3	2N338		
	Q 4	2N338		
Diodes	CR1	1N645		
	CR2	1N752A		5.6 V Zener
	CR3	1N645		

E. SACS CONTROL ELECTRONICS (Continued)

FULL TRIGGER - 4 MODULES: (Z3 & Z4), (Z5 & Z6), (Z7 & Z8), (Z9 & Z10)
Figure I-19.

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	½2N2223A		
	Q 2	½2N2223A		
	Q 3	½2N2223A		
	Q 4	½2N2223A		
	Q 5	2N338		
	Q 6	2N338		
	Q 7	2N338		
	Q 8	2N338		
Diodes				
	CR1	1N645		
	CR2	1N645		
	CR3	1N752A		5.6 V Zener
	CR4	1N752A		5.6 V Zener
	CR5	1N645		
	CR6	1N645		
Resistors	R 1	RC07GF202J	2	
	R 2	RC07GF431J	430Ω	
	R 3	RC07GF431J	430Ω	
	R 4	RN60B1502F	15	
	R 5	RN60B1502F	15	
	R 6	RN65E1002F	10	
	R 7	3010P-1-502	5	
	R 8	RN65E1002F	10	
	R 9	RC07GF154J	150	
	R10	RC07GF272J	2.7	
	R11	RC07GF272J	2.7	
	R12	RC07GF102J	1	
	R13	RC07GF272J	2.7	
	R14	RC07GF333J	33	
	R15	RC07GF153J	15	
	R16	RC07GF202J	2	
	R17	RC07GF431J	430Ω	
	R18	RC07GF431J	430Ω	
	R19	RN60B1502F	15	
	R20	RN60B1502F	15	
	R21	RN65E1002F	10	
	R22	3010P-1-502	5	
	R23	RN65E1002F	10	
	R24	RC07GF154J	150	
	R25	RC07GF272J	2.7	
	R26	RC07GF273J	27	

E. SACS CONTROL ELECTRONICS (Continued)

IULL TRIGGER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R27	RC07GF102J	1	
	R28	RC07GF272J	2.7	
	R29	RC07GF333J	33	
	R30	RC07GF153J	15	

F. JUNCTION BOX

Sketch 742-B-60, Figure I-11

Part Designation		Part No.	Value	Remarks
Relay	K 1	94GB13-4-A-1K		Electronic Specialty
Amplifier	A 1	1503		Burr Brown
Capacitors	C 1	TES300-50NX-P-1	300	International Elec Inc
	C 2	Disc	150μμf	
Resistors	R 1	RC07GF102J	1	
	R 2	RC07GF102J	1	
	R 3	RC07GF102J	1	
	R 4	RC07GF102J	1	
	R 5	RC07GF102J	1	
	R 6	RC07GF102J	1	
	R 7	RC07GF104J	100	
	R 8	RC07GF154J	150	
	R 9	RC07GF154J	150	
	R10	RC07GF103J	10	
Diodes	CR 1	1N1124A		
	CR 2	1N1124A		
	CR 3	1N1124A		
	CR 4	1N1124A		
	CR 5	1N1124A		
	CR 6	1N1124A		
	CR 7	1N1124A		
	CR 8	1N1124A		
	CR 9	1N1124A		

G. TELEMETRY SIGNAL CONDITIONER

Sketch 742-B-90, Figure I-9

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC07GF510J	51Ω	
	R 2	RC07GF753J	75	
	R 3	RC07GF473J	47	
	R 4	RC07GF753J	75	
	R 5	RC07GF473J	47	
	R 6	RC07GF124J	120	
	R 7	RC07GF104J	100	
	R 8	RC07GF623J	62	
	R 9	RC07GF512J	5.1	
	R10	RC07GF512J	5.1	
	R11	RC07GF512J	5.1	
	R12	RC07GF101J	100Ω	
	R13	RC07GF101J	100Ω	
	R14	RC07GF752J	7.5	
	R15	RW59G451	450Ω	2.5 W
	R16	RC07GF753J	75	
	R17	RC07GF753J	75	
	R18	RC07GF753J	75	
	R19	RC07GF753J	75	
	R20	RC07GF333J	33	
	R21	RC07GF333J	33	
	R22	RC07GF333J	33	
	R23	RC07GF333J	33	
	R24	RC07GF243J	24	
	R25	RN60B1503F	150	
	R26	RN60B1503F	150	
	R27	RN60B1003F	100	
	R28	RN60B1003F	100	
	R29	RN60B6042F	60.4	
	R30	3010P-1-502	5K	
	R31	RC07GF331J	330Ω	
	R32	RC20GF241J	240Ω	
	R33	RC07GF682J	6.8	
	R34	RC07GF682J	6.8	
	R35	RC07GF473J	47	
	R36	RC07GF241J	240Ω	
	R37	RC07GF751J	750Ω	
	R38	RC07GF751J	750Ω	
	R39	RC07GF512J	5.1	
	R40	RC07GF512J	5.1	
	R41	RC07GF512J	5.1	
	R42	RN60B1691F	1.69 Meg	
	R43	RC07GF512J	5.1	

G. TELEMETRY SIGNAL CONDITIONER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R44	RN60B6043F	604	
	R45	RC07GF622J	6.2	
	R46	RC07GF153J	15	
	R47	RC07GF153J	15	
	R48	RC07GF303J	30	
	R49	RC07GF303J	30	
	R50	RC07GF303J	30	
	R51	RC07GF302J	3	
	R52	RC07GF303J	30	
	R54	RC07GF303J	30	
	R55	RC07GF223J	22	
	R56	RC07GF223J	22	
	R57	RC07GF103J	10	
	R58	RC07GF103J	10	
	R59	RC07GF103J	10	
	R60	RC07GF103J	10	
	R61	RC07GF753J	75	
	R62	RC07GF473J	47	
	R63	RC07GF512J	5.1	
	R64	RC07GF512J	5.1	
	R65	RC07GF243J	24	
	R66	RC07GF912J	9.1	
	R67	RC07GF133J	13	
	R68	RC07GF305J	3 Meg	
	R69	RC07GF513J	51	
	R70	RC07GF305J	3 Meg	
	R71	RC07GF513J	51	
	R72	RC07GF514J	510	
	R73	RC07GF514J	510	
	R74	RC07GF912J	9.1	
	R75	RC07GF302J	3	
	R76	3010P-1-103	10	Bourns
	R77	RC07GF912J	9.1	
	R78	RC07GF302J	3	
	R79	3010P-1-103	10	Bourns
	R80	RC07GF512J	5.1	
	R81	RC07GF512J	5.1	
	R82	RC07GF512J	5.1	
	R83	RC07GF512J	5.1	
	R84	RC07GF912J	9.1	
	R85	RC07GF912J	9.1	
	R86	RC07GF512J	5.1	
	R87	RC07GF273J	27	
	R88	RC07GF512J	5.1	
	R89	RC07GF273J	27	
	R90	RC07GF512J	5.1	

G. TELEMETRY SIGNAL CONDITIONER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R91	RC07GF753J	75	
	R92	RC07GF473J	47	
	R93	RC07GF512J	5.1	
	R94	RC07GF753J	75	
	R95	RC07GF473J	47	
	R96	RC07GF512J	5.1	
	R97	RC07GF273J	27	
	R98	RC07GF512J	5.1	
	R99	RC07GF273J	27	
	R100	RC07GF512J	5.1	
	R101	RC07GF273J	27	
	R102	RC07GF512J	5.1	
	R103	RC07GF512J	5.1	
	R105	RC07GF912J	9.1	
	R107	RC07GF912J	9.1	
	R108	RC07GF302J	3	
	R110	RC07GF512J	5.1	
	R111	RN60B1694F	1.69 Meg	
	R112	RN60B6043F	604	
	R113	RN60B6042F	60.4	
	R114	RN60B1403F	140	
	R115	RN60B1403F	140	
	R116	RN60B1403F	140	
	R117	RN60B1403F	140	
	R118	RN60B1403F	140	
	R119	RN60B1503F	150	
	R120	RN60B1503F	150	
	R121	RN60B1503F	150	
	R122	RN60B1503F	150	
	R123	RN60B1503F	150	
	R124	RN60B1503F	150	
	R125	RN60B1503F	150	
Diodes	CR 1	1N943		11.7 V Zener
	CR 2	1N943		11.7 V Zener
	CR 3	1N751		5.1 V Zener
	CR 4	1N751		5.1 V Zener
	CR 5	1N677		
	CR 6	1N677		
	CR 7	1N677		
	CR 8	1N677		
	CR 9	1N750		4.7 V Zener
	CR10	1N767		
	CR11	1N767		
	CR12	1N457		
	CR13	1N457		

G. TELEMETRY SIGNAL CONDITIONER (Continued)

Part Designation		Part No.	Value	Remarks
Diodes	CR14	1N457		
	CR15	1N457		
	CR16	1N457		
	CR17	1N457		
	CR18	1N457		
	CR19	1N457		
	CR20	1N457		
	CR21	1N457		
	CR22	1N457		
	CR23	1N457		
	CR24	1N457		
	CR25	1N457		
	CR26	1N457		
	CR27	1N457		
	CR28	1N457		
	CR29	1N457		
	CR30	1N457		
	CR31	1N457		
	CR32	1N457		
	CR33	1N457		
	CR34	1N457		
	CR35	1N457		
	CR36	1N706A		5.8 V Zener
	CR37	1N706A		5.8 V Zener
	CR38	1N706A		5.8 V Zener
	CR39	1N706A		5.8 V Zener
	CR40	1N706A		5.8 V Zener
Capacitors	C 1	111D305X0050G1	3.0	Sprague
	C 2	111D305X0050G1	3.0	Sprague
	C 3	2DE1-104	0.1	Electron Products
	C 4	151D115X9035W2	1.1	Sprague
	C 5	151D115X9035W2	1.1	Sprague
	C 6	151D115X9035W2	1.1	Sprague
	C 7	151D115X9035W2	1.1	Sprague
	C 8	151D115X9035W2	1.1	Sprague
	C 9	151D115X9035W2	1.1	Sprague
	C10	151D115X9035W2	1.1	Sprague
	C11	151D115X9035W2	1.1	Sprague
	C12	150D226X0035	22	Sprague
	C13	150D226X0035	22	Sprague
	C14	150D474X9035A2	0.47	Sprague
	C15	150D474X9035A2	0.47	Sprague
	C16	150D685X9035B2	6.8	Sprague
	C17	150D474X9035A2	0.47	Sprague

G. TELEMETRY SIGNAL CONDITIONER (Continued)

Part Designation		Part No.	Value	Remarks
Capacitors	C19	150D474X9035A2	0.47	Sprague
	C20	150D685X9035B2	6.8	Sprague
	C22	150D474X9035A2	0.47	Sprague
	C23	150D685X9035B2	6.8	Sprague
	C24	150D474X9035A2	0.47	Sprague
	C25	150D474X9035A2	0.47	Sprague
	C26	150D685X9035B2	6.8	Sprague
	C27	2DE1-223	.022	Electron Products
	C28	2DE1-223	.022	Electron Products
Transistors	Q 1	2N1132		
	Q 2	2N1132		
	Q 3	2N1132		
	Q 4	2N1132		
Amplifiers	A 1	1503		Burr Brown
	A 2	1503		Burr Brown
	A 3	1503		Burr Brown
	A 4	1503		Burr Brown

H. GSE OVERALL

Sketch 742-D-10, Figure I-17

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	2N1613		
	Q 2	2N1613		
	Q 3	2N1613		
	Q 4	2N1613		
	Q 5	2N1613		
	Q 6	2N1613		
	Q 7	2N1613		
	Q 8	2N1613		
	Q 9	2N1613		
	Q10	2N1613		
	Q11	2N1613		
	Q12	2N1613		
	Q13	2N1613		
	Q14	2N1613		
	Q15	2N1613		
	Q16	2N1613		
	Q17	2N1613		
	Q18	2N1613		
	Q19	2N1613		
	Q20	2N1613		
	Q21	2N1613		
	Q22	2N1613		
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N645		
	CR 4	1N645		
	CR 5	1N645		
	CR 6	1N645		
	CR 7	1N645		
	CR 8	1N645		
	CR 9	1N645		
	CR10	1N645		
	CR11	1N645		
	CR12	1N645		
	CR13	1N645		
	CR14	1N645		
	CR15	1N645		
	CR16	1N645		
	CR17	1N645		
	CR18	1N645		
	CR19	1N645		
	CR20	1N645		

H. <u>GSE OVERALL</u> (Continued)

Part Designation		Part No.	Value	Remarks
Diodes	CR21	1N645		
	CR22	1N645		
	CR23	1N645		
	CR24	1N645		
	CR25	1N645		
	CR26	1N645		
	CR27	1N645		
	CR28	1N645		
	CR29	1N645		
	CR30	1N645		
	CR31	1N645		
Resistors	R 3	RC20GF104J	100	
	R 4	RC20GF474J	470	
	R 5	RC32GF332J	3.3	
	R 6	RC20GF123J	12	
	R 7	3010P-1-502	5	Bourns
	R 8	RC20GF273J	27	
	R 9	RC20GF224J	220	
	R10	RC32GF152J	1.5	
	R11	RC20GF472J	4.7	
	R12	RC07GF101J	100Ω	
	R13	RC07GF101J	100Ω	
	R14	RC07GF101J	100Ω	
	R15	RC07GF101J	100Ω	
	R16	RC07GF101J	100Ω	
	R17	RC07GF101J	100Ω	
	R18	RC07GF101J	100Ω	
	R19	RC07GF101J	100Ω	
	R20	RC07GF101J	100Ω	
	R21	RC20GF223J	22	
	R22	RC20GF274J	270	
	R23	RC20GF123J	12	
	R24	RC20GF223J	22	
	R25	RC20GF274J	270	
	R26	RC20GF123J	12	
	R27	RC20GF104J	100	
	R28	RC20GF474J	470	
	R29	RC32GF332J	3.3	
	R30	RC20GF123J	12	
	R31	RC20GF183J	18	
	R32	RC20GF183J	18	
	R34	RC20GF334J	330	
	R35	RC20GF123J	12	
	R 5A	RC20GF305J	3 Meg	

H. GSE OVERALL (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R36	RC20GF274J	270	
	R37	RC20GF153J	15	
	R38	RC07GF101J	100Ω	1/4 W
	R39	RC07GF101J	100Ω	1/4 W
	R40	RC20GF105J	1 Meg	
	R41	RC20GF394J	390	
	R42	RC20GF183J	18	
	R43	RC20GF623J	62	
	R44	RC20GF224J	220	
	R45	RC20GF223J	22	
	R46	RC32GF222J	2.2	1 W
	R47	RC20GF153J	15	
	R48	RC20GF623J	62	
	R49	RC32GF222J	2.2	1 W
	R50	RC20GF153J	15	
	R51	RC20GF623J	62	
	R52	RC20GF394J	390	
	R53	RC20GF183J	18	
	R54	RC20GF623J	62	
	R55	RC20GF394J	390	
	R56	RC20GF183J	18	
	R57	RC20GF623J	62	
Light Bulbs	L 1	NE51		120 VAC NEON
	L 2	NE51		120 VAC NEON
	L 3	TYPE 327		0.04A, At 28 VDC
	L 4	TYPE 327		0.04A, At 28 VDC
	L 5	TYPE 327		0.04A, At 28 VDC
	L 6	TYPE 327		0.04A, At 28 VDC
	L 7	TYPE 327		0.04A, At 28 VDC
	L 8	TYPE 327		0.04A, At 28 VDC
	L 9	TYPE 327		0.04A, At 28 VDC
	L10	TYPE 327		0.04A, At 28 VDC
	L11	TYPE 327		0.04A, At 28 VDC
	L12	TYPE 327		0.04A, At 28 VDC
	L13	TYPE 327		0.04A, At 28 VDC
	L14	TYPE 327		0.04A, At 28 VDC
	L15	TYPE 327		0.04A, At 28 VDC
	L16	TYPE 327		0.04A, At 28 VDC
	L17	TYPE 327		0.04A, At 28 VDC
	L18	TYPE 327		0.04A, At 28 VDC
	L19	TYPE 327		0.04A, At 28 VDC
	L20	TYPE 327		0.04A, At 28 VDC
	L21	TYPE 327		0.04A, At 28 VDC
	L22	TYPE 327		0.04A, At 28 VDC

H. GSE OVERALL (Continued)

Part Designation		Part No.	Value	Remarks
Light Bulbs	L23	TYPE 327		0.04A At 28 VDC
	L24	TYPE 327		0.04A At 28 VDC
	L25	TYPE 327		0.04A At 28 VDC
	L26	TYPE 327		0.04A At 28 VDC
	L27	TYPE 327		0.04A At 28 VDC
	L28	TYPE 327		0.04A At 28 VDC
	L29	TYPE 327		0.04A At 28 VDC
	L30	TYPE 327		0.04A At 28 VDC
	L31	TYPE 327		0.04A At 28 VDC
	L32	TYPE 327		0.04A At 28 VDC
	L33	TYPE 327		0.04A At 28 VDC
	L34	TYPE 327		0.04A At 28 VDC
	L35	TYPE 327		0.04A At 28 VDC
	L36	TYPE 327		0.04A At 28 VDC
Fuses	F 1	5 AMP		
	F 2	0.75 AMP		
	F 3	0.75 AMP		
Meters	M 1	Mod No. 1145		(0-50 VDC) Volts
	M 2	Mod No. 1145		(0-30A F.S.) Current
Switches	S 1	DPST		Toggle Switch
	S 2	DPST		Toggle Switch
	S 3	DPST		Toggle Switch
	S 4	JV9002		Centralab
	S 5	RS406-12		Langevin
	S 6	DPDT		Toggle Switch
	S 7	W101/P adapter		SCC of America
	S 8	W101/P adapter		SCC of America
	S 9	W101/P adapter		SCC of America
	S10	W101/P adapter		SCC of America
Auxiliary Power Supply		Model SR 284		Electron Research Assoc. Inc.
Main Power Supply		Model 814A		Harrison Lab.
Relays	K 1	JDP 246 C24		C.P. Clare & Co.

I. GSE CAGING CONTROL CHANNELS

Sketch 742-D-30, Figure I-18

NOTE: ROLL, PITCH, & YAW CHANNELS ARE THE SAME

Part Designation		Part No.	Value	Remarks
Resistors	R 1	RC20GF103J	10	
	R 2	RC20GF103J	10	
	R 3	RC20GF753J	75	
	R 4	RC20GF753J	75	
	R 5	RC20GF305J	3 Meg	
	R 6	RC20GF821J	820Ω	
	R 7	RC20GF822J	8.2	
	R 8	RC20GF821J	820Ω	
	R 9	RC20GF822J	8.2	
	R10	RC20GF272J	2.7	
	R11	RC20GF392J	3.9	
	R12	RC20GF104J	100	
	R13	RC20GF392J	3.9	
	R14	RC20GF272J	2.7	
	R15	RC20GF332J	3.3	
	R16	RC20GF123J	12	
	R17	3010P-1-502	5	Bourns
	R18	3010P-1-502	5	Bourns
	R19	3010P-1-502	5	Bourns
	R20	RC20GF823J	82	
	R21	RC20GF394J	390	
	R22	RC20GF105J	1 Meg	
	R23	RC20GF624J	620	
Transformer	T 1	MMT-27-FB		
Amplifiers	A 1	1503		Burr Brown
	A 2	1506		Burr Brown
Control Transformers		TYPE CTH-15-D-15		Clifton Precision Products
Transistors	Q 1	2N1613		
	Q 2	2N1613		
	Q 3	2N338		
	Q 4	2N1613		
	Q 5	2N338		
	Q 6	2N1613		
	Q 7	2N656		
	Q 8	2N1486		

I. <u>GSE CAGING CONTROL CHANNELS</u> (Continued)

Part Designation		Part No.	Value	Remarks
<u>Diodes</u>	CR 1	1N457		
	CR 2	1N457		
	CR 3	1N645		
	CR 4	1N645		
	CR 5	1N645		
	CR 6	1N645		
	CR 7	1N645		
	CR 8	1N645		
<u>Switches</u>	S 1	A3-77-T3		SCC of America
	S 2	A3-77-T3		SCC of America
	S 3	A3-77-T3		SCC of America
	S 4	399223A		QAK
	S 5	399223A		QAK
	S 6	399223A		QAK
	S 7	W101/P adapter		SCC of America
<u>Relays</u>	K 1	93GB61-4-A-480		
	K 2	93GB61-4-A-480		
	K 3	JDP 246 C24		C.P. Clare
<u>Capacitors</u>	C 1	2DE1-105	1	
	C 2	2DE1-105	1	
	C 3	2DE1-682	.0068	
	C 4	Disc	10μμf	

I. GSE CAGING CONTROL CHANNELS (Continued)

FULL TRIGGER
Figure I-19

Part Designation	Part No.	Value	Remarks
Transistors Q 1	½ 2N2223A		
Q 2	½ 2N2223A		
Q 3	½ 2N2223A		
Q 4	½ 2N2223A		
Q 5	2N338		
Q 6	2N338		
Q 7	2N338		
Q 8	2N338		
Diodes CR 1	1N645		
CR 2	1N645		
CR 3	1N752A		5.6V Zener
CR 4	1N752A		5.6V Zener
CR 5	1N645		
CR 6	1N645		
Resistors R 1	RC07GF202J	2K	
R 2	RC07GF431J	430Ω	
R 3	RC07GF431J	430Ω	
R 4	RN60B1502F	15	
R 5	RN60B1502F	15	
R 6	RN65E1002F	10	
R 7	3010P-1-502	5	Bourns
R 8	RN65E1002F	10	
R 9	RC07GF154J	150	
R10	RC07GF272J	2.7	
R11	RC07GF272J	2.7	
R12	RC07GF102J	1	
R13	RC07GF272J	2.7	
R14	RC07GF333J	33	
R15	RC07GF153J	15	
R16	RC07GF202J	2	
R17	RC07GF431J	430Ω	
R18	RC07GF431J	430Ω	
R19	RN60B1502F	15	
R20	RN60B1502F	15	
R21	RN65E1002F	10	
R22	3010P-1-502	5	Bourns
R23	RN65E1002F	10	
R24	RC07GF154J	150	
R25	RC07GF272J	2.7	
R26	RC07GF273J	27	

I. GSE CAGING CONTROL CHANNELS (Continued)

FULL TRIGGER (Continued)

Part Designation		Part No.	Value	Remarks
Resistors	R27	RC07GF102J	1	
	R28	RC07GF272J	2.7	
	R29	RC07GF333J	33	
	R30	RC07GF153J	15	

I. GSE CAGING CONTROL CHANNELS (Continued)

DEMODULATORS
Figure I-23

Part Designation		Part No.	Value	Remarks
Transistors	Q 1	2N498		
	Q 2	2N498		
	Q 3	2N498		
	Q 4	2N498		
Diodes	CR 1	1N645		
	CR 2	1N645		
	CR 3	1N645		
	CR 4	1N645		

J. GSE DC POWER SUPPLY

Sketch 742-D-20, Figure I-16.

Part Designation		Part Number	Value	Remarks
Resistors	R 1	RC07GF103J	10	
	R 2	RC07GF332J	3.3	
	R 3	RN65E8251F	8.25	
	R 4	RN60B1301F	1.3	
	R 5	RN60B1502F	15	
	R 6	RN60B3921F	3.92	
	R 7	RN60B1502F	15	
	R 8	RN60B8251F	8.25	
	R 9	3010P-1-202	2	Bourns
	R10	RN65E5761F	5.76	
	R11	5%-TYPE AS-2-2W	0.47Ω	IRC
	R1A	RC07GF103J	10	
	R2A	RC07GF332J	3.3	
	R3A	RN65E8251F	8.25	
	R4A	RN60B1301F	1.3	
	R5A	RN60B1502F	15	
	R6A	RN60B3921F	3.92	
	R7A	RN60B1502F	15	
	R8A	RN60B8251F	8.25	
	R9A	3010P-1-202	2	Bourns
	R10A	RN65E5761F	5.78	
	R11A	5%-TYPE AS-2-2W	0.47Ω	IRC
Capacitors	C 1	MG1-224	0.22	Electron Products
	C 2	150D476X0035S2	47	Sprague
	C 1A	MG1-224	0.22	Electron Products
	C 2A	150D476X0035S2	47	Sprague
Diodes	CR 1	1N827		6.2 V Zener
	CR 1A	1N827		6.2 V Zener
Transistors	Q 1	2N1486		
	Q 2	2N656		
	Q 3	2N2223A		
	Q 4	2N2223A		
	Q 5	2N656		
	Q 1A	2N1486		
	Q 2A	2N656		
	Q 3A	2N2223A		
	Q 4A	2N2223A		
	Q 5A	2N656		

Appendix III

PNEUMATIC ANALYSIS OF AEROBEE ACS FORCE CONTROL SYSTEM

A. SUMMARY

This appendix presents the results of an analysis of the Aerobee ACS force control system. The system characteristics are shown in both tabular and flow chart form, including curves of valve response time and vehicle acceleration in each of the three axes. All symbols are identified in Table III-1.

B. INTRODUCTION

The force control system of the ACS consists of a helium gas supply tank, the flow control valves, the thrust nozzles, and the associated plumbing. The system is shown schematically in Figure III-1. The propulsion system pressurizing gas is used as the gas supply, the residual helium being drawn from the propulsion system tankage for coast attitude control after the end of powered flight.

Two nozzle pairs are used for control about the roll axis. The flow through each nozzle pair is controlled by a single solenoid valve. In addition a solenoid valve is connected in parallel with the CCW control valve to despin the vehicle after burnout. The roll control and despin portion of the force control system is located in the ACS insert and is connected to the propulsion system in the regulator compartment. The connection is made directly to the pressurization line leading to the aft propellant tank. Since the initial use of gas is for despin, this prevents the pressure in the forward propellant tank from becoming lower than that in the aft tank, thereby preventing collapse of the common bulkhead. Burst diaphragms are provided between the ACS and the propulsion system to prevent the propellants from contaminating the roll control valves prior to launch. These diaphragms are broken when the propellant tanks are pressurized at lift-off.

The pitch/yaw portion of the force control system is located in the aft tail structure of the vehicle and is physically independent of the ACS insert, the only connection being the electrical signals used to operate the solenoid valves. One thrust nozzle is used with each valve for CCW control and one valve and nozzle for CW control in each axis.

Since the line of thrust of the control jet acts through the longitudinal center-line of the vehicle, a true force couple is not needed to prevent coupling between the pitch/yaw axis and the roll axis. The pitch valves and yaw valves are connected to separate tanks to minimize the flow in each supply line, thus minimizing the pressure drop. Pressure taps for this purpose are provided in the lines between the tankage and the thrust chamber assembly. Again, burst diaphragms are provided for the purpose of isolating the control valves from the propellant prior to flight.

C. ANALYSIS

The pneumatic analysis of the ACS may be divided into two separate sections: the pitch/yaw force control system and the roll force control system. However, even though the operational parameters of the two subsystems differ, they may be treated in the same manner. Therefore, the pitch/yaw circuit will be analyzed in detail and the roll circuit will be described only as it differs from the pitch/yaw system.

The problems involved in this flow analysis are those of subsonic flow of a compressible viscous fluid in a pipe and the sonic flow of a gas through an orifice. Since both of these occur in the same circuit, the rigorous solution of the steady-state flow is a laborious task. To simplify this task several assumptions are made. As shown in Reference III-1, the isothermal flow of a gas may be approximated by assuming that the gas behaves as an incompressible fluid. A comparison of the two cases, which is valid for small pressure drops, is

$$\text{(compressible)} \quad \frac{P_1 - P_2}{P_1} = 1 - \sqrt{1 - 2B} \qquad \text{(III-1)}$$

$$\text{(incompressible)} \quad \frac{P_1 - P_2}{P_1} = B \qquad \text{(III-2)}$$

where

$$B = \frac{f\lambda V_1^2}{2gDP_1 v_1} \qquad \text{(III-3)}$$

Rewriting Equations (III-1) and (III-2) in terms of N_m we find that

$$\text{(compressible)} \quad \frac{P_1 - P_2}{P_1} = 1 - \sqrt{1 - \frac{f\lambda k}{2D} (N_m)^2} \qquad \text{(III-1a)}$$

$$\text{(incompressible)} \quad \frac{P_1 - P_2}{P_1} = \frac{f\lambda k}{2D} (N_m)^2 \qquad \text{(III-2a)}$$

where $\frac{f\lambda k}{2D}$ is assumed constant for any given section and gas. If the pressure drop for compressible flow is plotted versus incompressible flow for different Mach numbers, comparison of these two equations shows that for Mach numbers less than 0.20 and pressure drops of 10 to 20% of the initial pressure, the error in determination of pressure drop is approximately 5%. Since the variation in the condition of the residual helium at the end of powered flight causes an uncertainty larger than 5% in the operating parameters and the tolerance in the flow through the control valves is ± 10%, the assumption of incompressible flow is certainly justified. From the above conclusion a formula for relating tank pressure directly to vehicle angular acceleration may be developed, thus eliminating the reiterative process:

$$\alpha = \frac{\tau}{I} \qquad \text{(III-4)}$$

$$\tau = FL \qquad \text{(III-5)}$$

$$F = \dot{\omega} \ ISP \qquad \text{(III-6)}$$

$$\dot{\omega} = \frac{0.2093 \ C_D A P_2}{\sqrt{T}} = M_1 P_2 \ \text{(for helium)} \qquad \text{(III-7)}$$

$$P_2 = P_1 - \Delta P \qquad \text{(III-8)}$$

$$\Delta P = \frac{3.623 \ (\dot{\omega})^2}{\omega_{sp}} \left(\frac{K}{D^4} \right) \qquad \text{(III-9)}$$

$$= \frac{M_2 \ (M_1 P_2)^2}{M_3 P_1} \qquad \text{(III-10)}$$

where

$$\omega_{sp} = \frac{P_1}{RT_1} = M_3 P_1 \qquad \text{(III-11)}$$

Substituting Equation (III-10) into Equation (III-8) we get

$$P_2 = P_1 - \frac{M_2 (M_1 P_2)^2}{M_3 P_1} \tag{III-12}$$

$$M_3 P_1 P_2 = M_3 P_1^{\,2} - M_2 M_1 P_2^{\,2} \tag{III-13}$$

and solving for P_2:

$$P_2 = \frac{-M_3 P_1 \pm \sqrt{(M_3 P_1)^2 + 4\,(M_3 M_1^{\,2})\,(M_3 P_1^{\,2})}}{2 M_2 M_1^{\,2}} \tag{III-14}$$

Also, since negative pressure does not exist the only physical solution of Equation (III-14) is

$$P_2 = \frac{P_1}{2 M_2 M_1^{\,2}} \sqrt{M_3^{\,2} + 4\,(M_1^{\,2} M_2 M_3)} - M_3 \tag{III-15}$$

Solving Equation (III-4) in terms of P_1 we get

$$\alpha = \frac{L\,(ISP)(P_1)\left[\left(\sqrt{\left(\frac{1}{RT}\right)^2 + 4\left(\frac{0.2093 C_D A}{\sqrt{T}}\right)^2 \left(3.623\,\frac{K}{D^4}\right)\left(\frac{1}{RT}\right)}\right) - \frac{1}{RT}\right]}{2\left(3.623\,\frac{K}{D^4}\right)\left(\frac{0.2093\ C_D A}{\sqrt{T}}\right) I} \tag{III-16}$$

It is assumed in Equation (III-16) that the only variable for each pneumatic circuit is P_1. Thus, for each circuit the factors such as ISP, $C_D A$ $\frac{K}{D^4}$, etc., must be established.

The ISP for pure helium has been established by altitude tests at 152 sec for the roll thrust nozzles and 159 sec for the pitch/yaw nozzles. The roll nozzle ISP is reduced due to impingement of the jet stream on the vehicle skin. As the thrust of the roll jets is tangential to the vehicle skin, their location is a compromise between a loss of ISP and extending the nozzles further into the air stream. At the present time the frictional heating of the nozzles is held to acceptable levels and extending them further from the skin would raise the nozzle surface temperature. Since the thrust of the pitch/yaw jets is at right angles to the vehicle skin, this impingement loss does not exist with these nozzles.

The C_DA (effective area for each control valve - pitch/yaw, roll control, and despin) was obtained from the control specification, SGC 71009. These values are listed in Tables III-2 and III-3.

The last item, $\frac{K}{D^4}$, is the most complex. Since $K = \frac{f\lambda}{D}$ and $\frac{\lambda}{D}$ remain constant for a given length of tubing it is apparent that K will vary as the friction factor. Reference III-1 plots the friction factor as a function of N_R. Since N_R varies directly as the pressure, it is seen that the pressure loss due to piping friction will vary slightly with pressure. This variation, as shown by tests, will amount to 10% of the pressure drop. This will represent an uncertainty in the mass flow through the nozzles of about 1.5%. To determine the actual loss coefficient for the pitch/yaw circuit, laboratory tests were run and $\frac{K}{D^4}$ calculated for both the total circuit and individual components. As test data indicated that the tubing used has a higher friction factor than estimated, all pressure drops in the pitch/yaw circuit were calculated using the test data. The friction factors obtained from the pitch/yaw tests were used in calculations for the roll circuit. This friction factor remains constant between a tank pressure of 300 to 500 psia and increases at pressures less than 300 psia. Therefore, the friction factor remains essentially constant over the majority of the range of interest. The complete hydraulic resistance diagram is shown in Figure III-2.

The curves of Figures III-3 and III-4 represent the graphical solution of Equation (III-16). In Figure III-5, the roll control acceleration was calculated from Equation (III-7) since the pressure drop between the tank and the inlet to the roll control manifold is less than 1 psi.

Calculation of the nozzle characteristics is independent of the remainder of the circuit as sonic flow first occurs at the control valve seat. Thus the flow rate is independent of conditions downstream of the valve seat as long as the pressure ratio across the valve seat remains less than 0.48 (Helium only). To accomplish this the only requirement is that the $C_D A$ of the nozzle throat be large enough to permit the required flow rate at a low enough chamber pressure. The nozzle characteristics are listed in Tables III-2 and III-3. Figures III-6 to III-8 show chamber pressure as a function of tank pressure.

Figures III-9 to III-12 show the response time of the control valves as a function of inlet pressure and temperature. To these times must be added the pressure build up and decay time constants of the nozzles. In the case of the pitch/yaw valves, this time constant is smaller than the time constant of the roll circuit since there is less ullage volume downstream of the control valve. The equation for the force buildup of the pneumatic system is:

$$F(t) = ISP\,\dot{\omega}\left[1 - \exp\left(-\frac{0.2093\,(C_D A)_{noz}\,R\,\sqrt{T}}{V_{ull}}\right)t\right] \qquad \text{(III-17)}$$

For the thrust tail-off the expression is:

$$F(t) = ISP\,\dot{\omega}\left[\exp\left(-\frac{0.2093\,(C_D A)_{noz}\,R\,\sqrt{T}}{V_{ull}}\right)t\right] \qquad \text{(III-18)}$$

and the time constant is:

$$\frac{V_{ull}}{0.2093\,(C_D A)_{noz}\,R\,\sqrt{T}} \qquad \text{(III-19)}$$

The characteristic time constants for each circuit are listed in Tables III-2 and III-3.

Attention is drawn to the point that all the above values are based on the use of pure helium gas. The flow rates, ISP, pressure drops, etc., are calculated for a gas with a specific heat ratio (k) of 1.66. In the vehicle this condition does not exist since the helium has been contaminated with the propellants. Since the relative acceleration between the propellants and the vehicle tankage is small (~ 0.04 g), this contamination may come about by either of two methods. The one generally assumed is that the residual propellants, if any, drift to the forward end of the tanks, leaving a mixture of propellant vapor and helium at the valve pressure tap. The other possibility is that the residual propellants may either be dispersed as a fine mist or the liquid may be located at the valve pressure tap. In this case liquid may flow through the ACS control valves and nozzles, instantly vaporizing upon passing the nozzle throat. This vapor acts as a gas with a specific heat ratio different from that of He. Since the Aerobee hydraulic circuit is normally balanced for a fuel exhaustion shutdown, the greatest possibility of liquid finding its way into the control valve pneumatic circuit exists in the oxidizer tank. Some evidence of this has been noted in previous Aerobee 150 flights, as shown by pitch jet gas impingement on the vehicle fins. However, since the probability of expelling liquid through the control jets appears low, the case of flowing a propellant vapor-helium gas combination through the jets appears to be the typical situation. As the vapor pressure of both propellants is below 0.1 atmosphere (Reference III-2) and the tank pressure is greater than 30 atmospheres, the percentage of vapor contained in the mixture is very small (.3%). Thus, the mixture may be treated as pure helium gas.

D. SAMPLE CALCULATION OF NOZZLE CHAMBER PRESSURE

During the solution of Equation (III-16) the expression for mass flow rate in terms of tank pressure was found:

$$\dot{\omega} = P_1 \left\{ \frac{\left[\sqrt{\left(\frac{1}{RT}\right)^2 + 4\left(\frac{0.2093\, C_D A}{\sqrt{T}}\right)^2 \left(3.623\, \frac{K}{D^4}\right)\left(\frac{1}{RT}\right)} \,\right] - \frac{1}{RT}}{2\left(3.623\, \frac{K}{D^4}\right)\left(\frac{0.2093\, C_D A}{\sqrt{T}}\right) I} \right\} \qquad \text{(III-20)}$$

This expression is suitable for the pitch/yaw and despin circuits. For roll control, Equation (III-7) may be used for flow rate versus tank pressure. Note that only half the total flow rate goes through each nozzle in the roll circuit.

The numerical values for $\dot{\omega}$, in terms of tank pressure, of each nozzle are

Pitch/yaw

$$\dot{\omega}_{noz} = 0.518 \times 10^{-4}\, P_1 \qquad \text{(III-21)}$$

Despin

$$\dot{\omega}_{noz} = 0.107 \times 10^{-3} P_1 \tag{III-22}$$

Roll control

$$\dot{\omega}_{noz} = 0.134 \times 10^{-4} P_1 \tag{III-23}$$

Since Equation (III-7) is the general equation for sonic flow of helium through a nozzle it may be rearranged to give chamber pressure in terms of weight flow:

$$P_C = \frac{\dot{\omega}_{noz} \sqrt{T}}{0.2093\ C_D A} \tag{III-24}$$

Substituting Equations (III-21) through (III-23) into Equation (III-24) and using the proper $C_D A$ for each nozzle (a constant temperature of $520^{\circ}R$ is used), the following equations for nozzle chamber pressure in terms of tank pressure are found:

Pitch/yaw

$$P_C = 0.204\ P_1 \tag{III-25}$$

Roll control

$$P_C = 4.49 \times 10^{-2}\ P_1 \tag{III-26}$$

Despin

$$P_C = 0.360\ P_1 \tag{III-27}$$

For example, if tank pressure = 400 psia, chamber pressure is as follows:

Circuit	Chamber Pressure (psia)
Pitch/Yaw	81.6
Roll	18.0
Despin	144.0

The graphs of these equations are presented in Figures III-6, III-7, and III-8.

REFERENCES

III-1. Binder, R. C., "Fluid Mechanics," Prentice-Hall, Inc., New York, 1949, 2nd Edition.

III-2. "Space Flight Technical Data," Aerojet-General Corp., Azusa, California, 1961.

Table III-1

SYMBOL IDENTIFICATION

Symbol	Description	Units
P_1	Tank pressure	psia
P_2	Valve inlet pressure	psia
f	Friction factor	
λ	Line length	in.
V_1	Inlet velocity	ft/sec
g	Gravity constant	32.2 ft/sec^2
D	Diameter	in.
v_1	Specific volume	ft^3/lb
α	Angular acceleration	deg/sec^2
τ	Torque	ft-lb
I	Moment of inertia	slug-ft^2
L	Lever arm	12.5 ft
F	Thrust	lb
$\dot{\omega}$	Flow rate	lb/sec
C_DA	Effective area	in.^{2}
T	Temperature	^oR
ΔP	Pressure difference	psi
ω_{sp}	Specific weight	lb/ft^3
K	Constant, $f \frac{\lambda}{D}$	-
R	Specific gas constant, He	386.3 ft/^{o}I
ISP	Specific impulse	sec
V_{ull}	Volume between valve seat and nozzle throat	in.^{3}
N_m	Mach number	-
k	Specific heat ratio	-
M_1	$\frac{0.2093\ C_DAP_2}{\sqrt{T}}$	lb/sec

Table III-1 (Continued)

SYMBOL IDENTIFICATION

Symbol	Description	Units
M_2	$3.623\left(\frac{K}{D^4}\right)$	$in.^{-4}$
M_3	$\frac{1}{RT_1}$	ft^{-1}
N_R	Reynolds number	-

Table III-2

PITCH/YAW CIRCUIT PARAMETERS

1. Valve Per AGC Spec 71009

   a. P.N. 13535

   b. Vendor: Allen Engineering, Burbank, California

   c. Flow rate

      0.0175 to 0.0215 lb/sec He
      at $60^{\circ}F$ and 300 ± 15 psia, 15 psia
      back pressure

   d. Response time (maximum)

      open 50 ms
      close 20 ms

2. Pitch/Yaw Nozzles

   a. Effective throat area 0.0275 $in.^2$

   b. Throat dia. 0.192 in.

   c. Area ratio: 18 to 1

   d. Exit angle: $9^{\circ}\ 40'$

   e. Characteristic time constant - $.5 \times 10^{-4}$ sec

Table III-3

ROLL CIRCUIT PARAMETERS

A. Valves

1. Despin Valve Per AGC Spec 71009

   Spec flow rate: 0.0755 to 0.0818 lb/sec He at $60^{\circ}F$ at 300 ± 15 psia inlet, 15 psia back pressure

2. Response time

Open-Max	Close-Max
70 ms	70 ms

3. Vendor: Futurecraft Corp., El Monte, California

4. Service

   P/N 20435-2 to be used with analine - furfuryl alcohol (Aerobee 150)

   P/N 20435-4 to be used with IRFNA (Aerobee 150A)

B. Roll Control Valves

1. Spec flow rate: 0.0070 to 0.0085 lb/sec He at $60^{\circ}F$ at 300 ± 15 psia inlet, 15 psia back pressure

2. Response time

Open-Max	Close-Max
50 ms	10 ms

3. Vendor: Allen Engineering Company, Burbank, California

4. Service is either furfuryl alcohol - analine or IRFNA

C. Roll Control Nozzles

1. Effective throat area: 0.0341 $in.^2$
2. Throat diameter: 0.208 in.
3. Area ratio: 15.7
4. Exit angle: $9^{\circ}\ 40'$
5. C_D 0.95
6. Characteristic time constant 7.05×10^{-4} sec

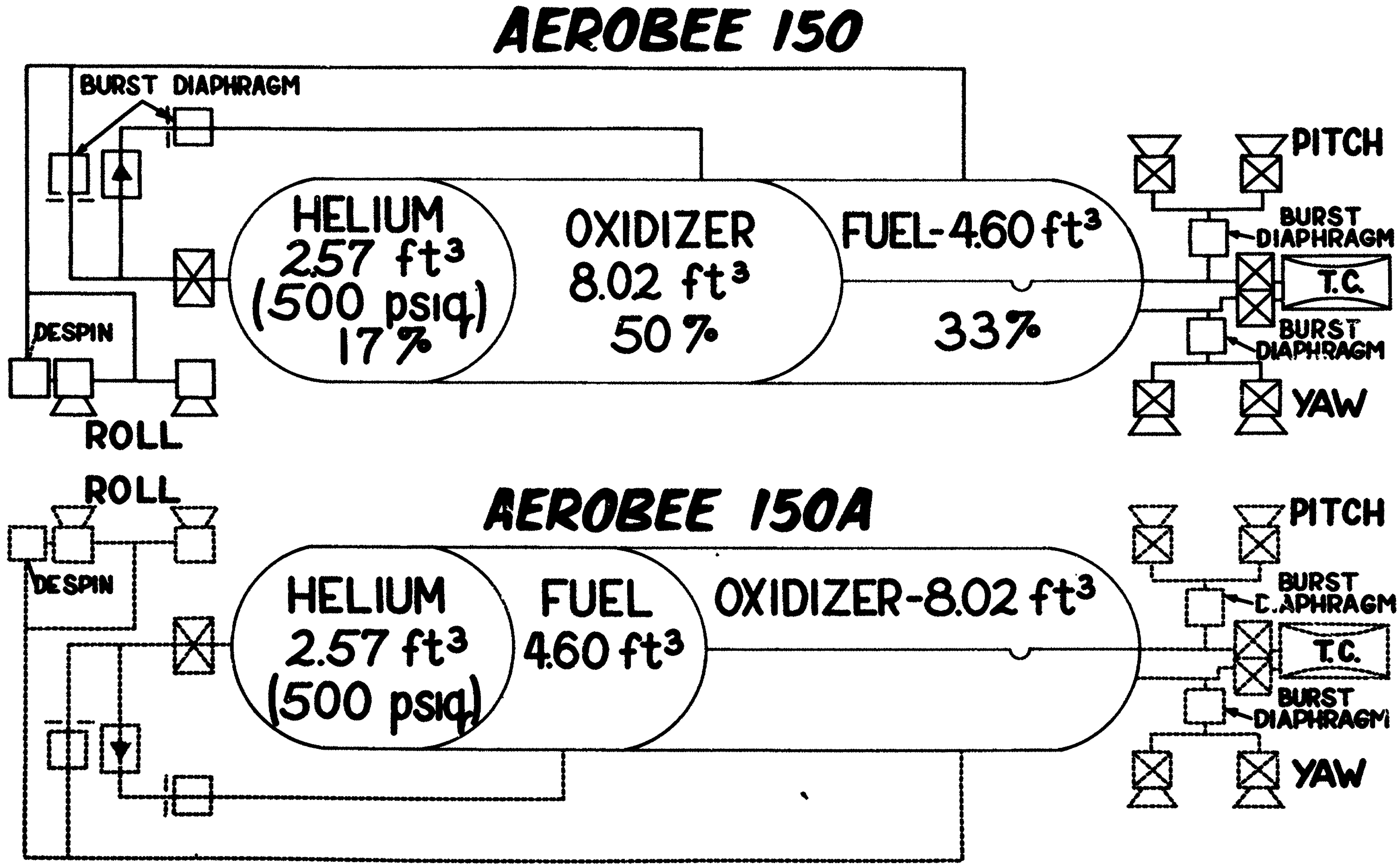


Figure III-1. Aerobee 150 ACS Pneumatic System

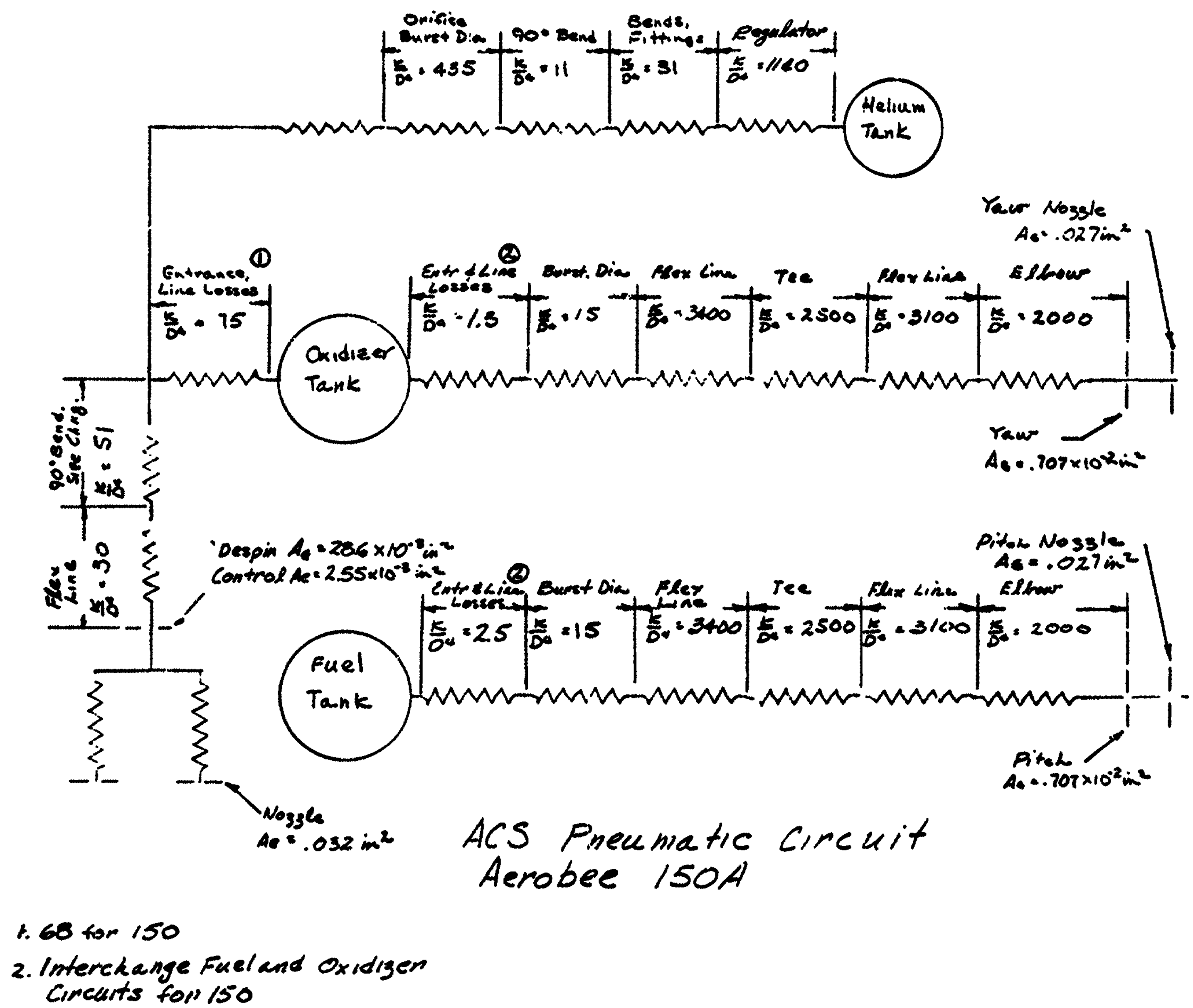


Figure III-2. Aerobee 150A ACS Pneumatic Circuit

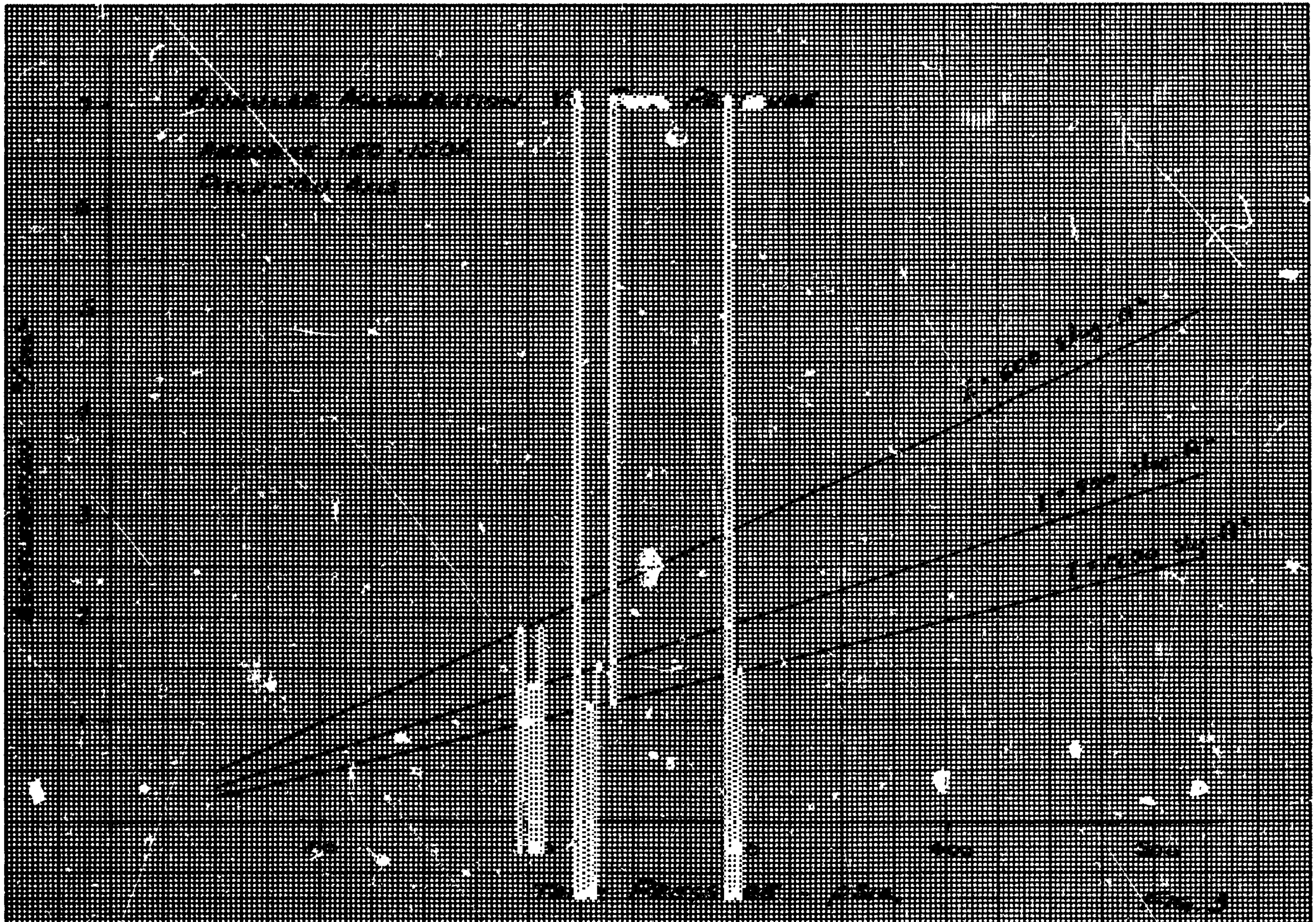


Figure III-3. Angular Acceleration Versus Tank Pressure, Aerobee 150-150A, Pitch/Yaw Axis

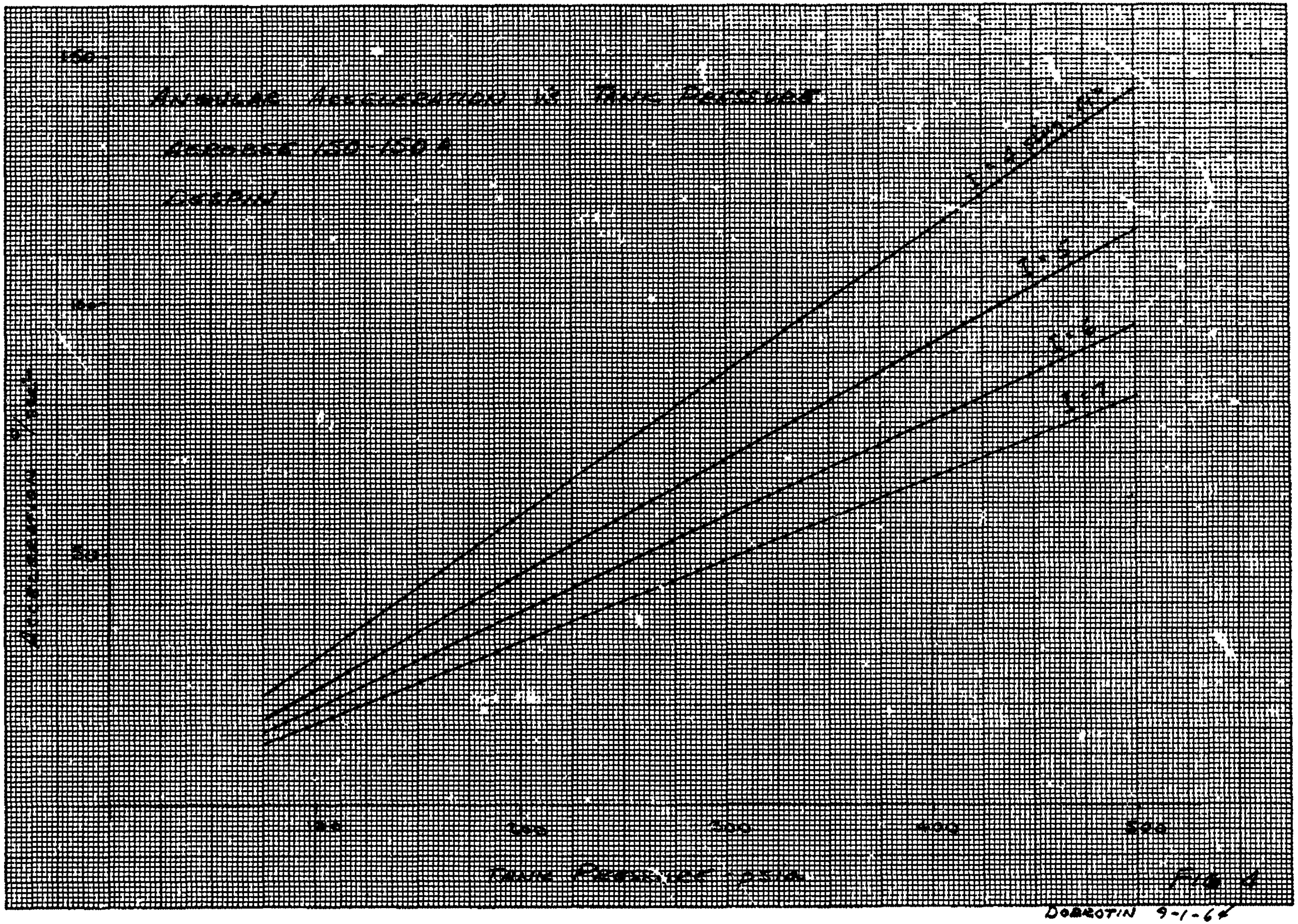


Figure III-4. Angular Acceleration Versus Tank Pressure, Aerobee 150-150A, Despin

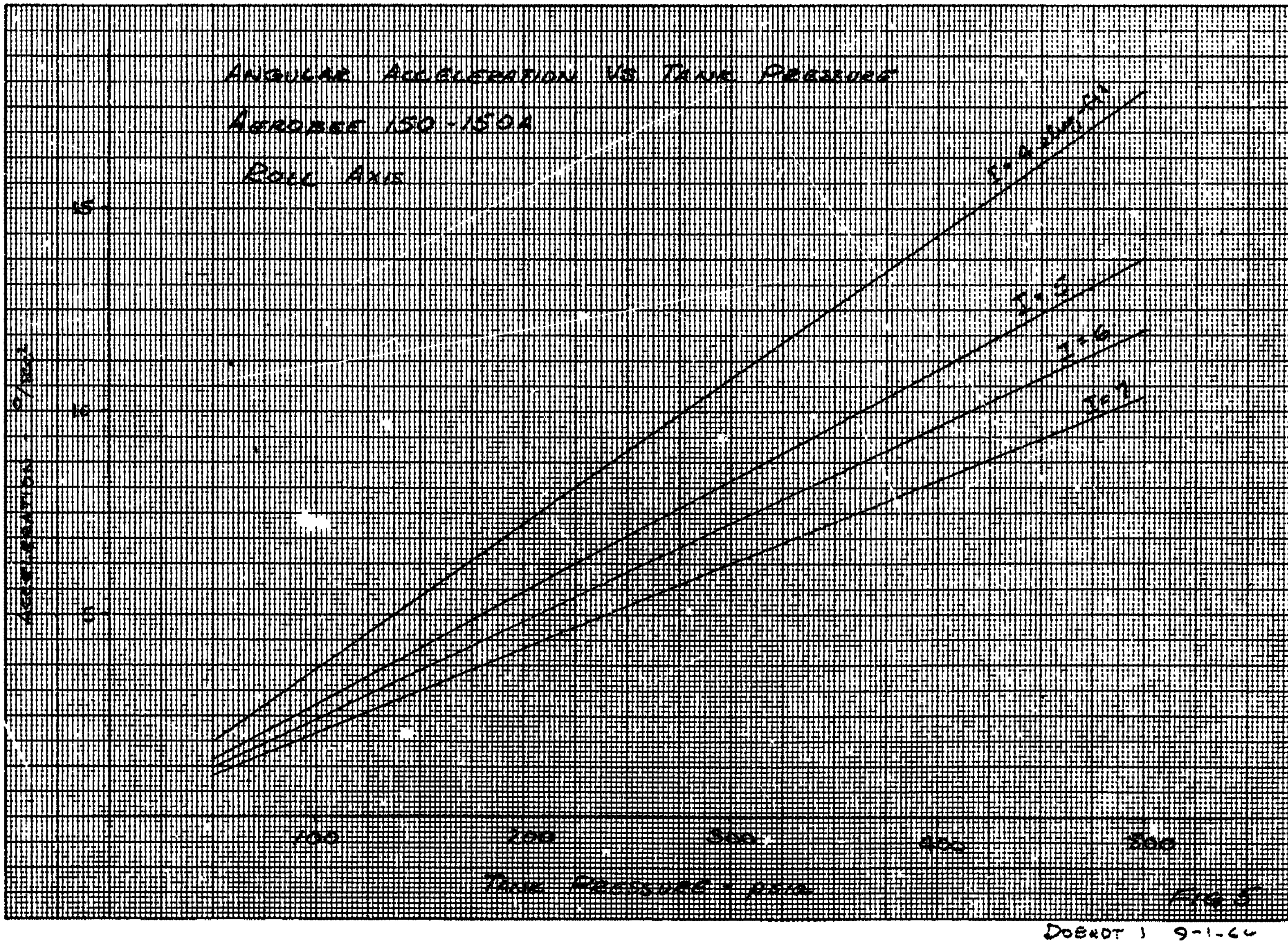


Figure III-5. Angular Acceleration Versus Tank Pressure, Aerobee 150-150A, Roll Axis

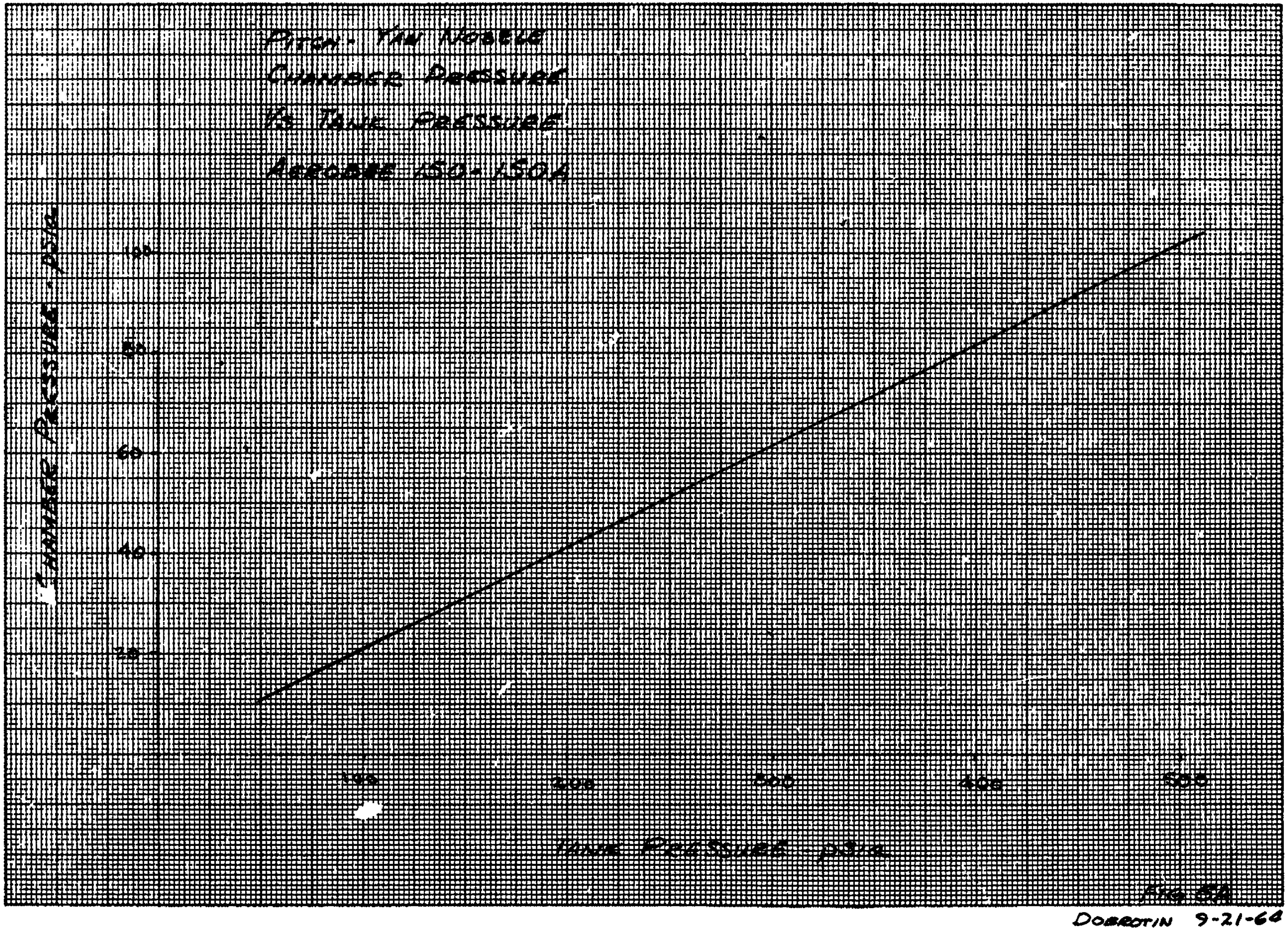


Figure III-6. Pitch/Yaw Nozzle Chamber Pressure Versus Tank Pressure, Aerobee 150-150A

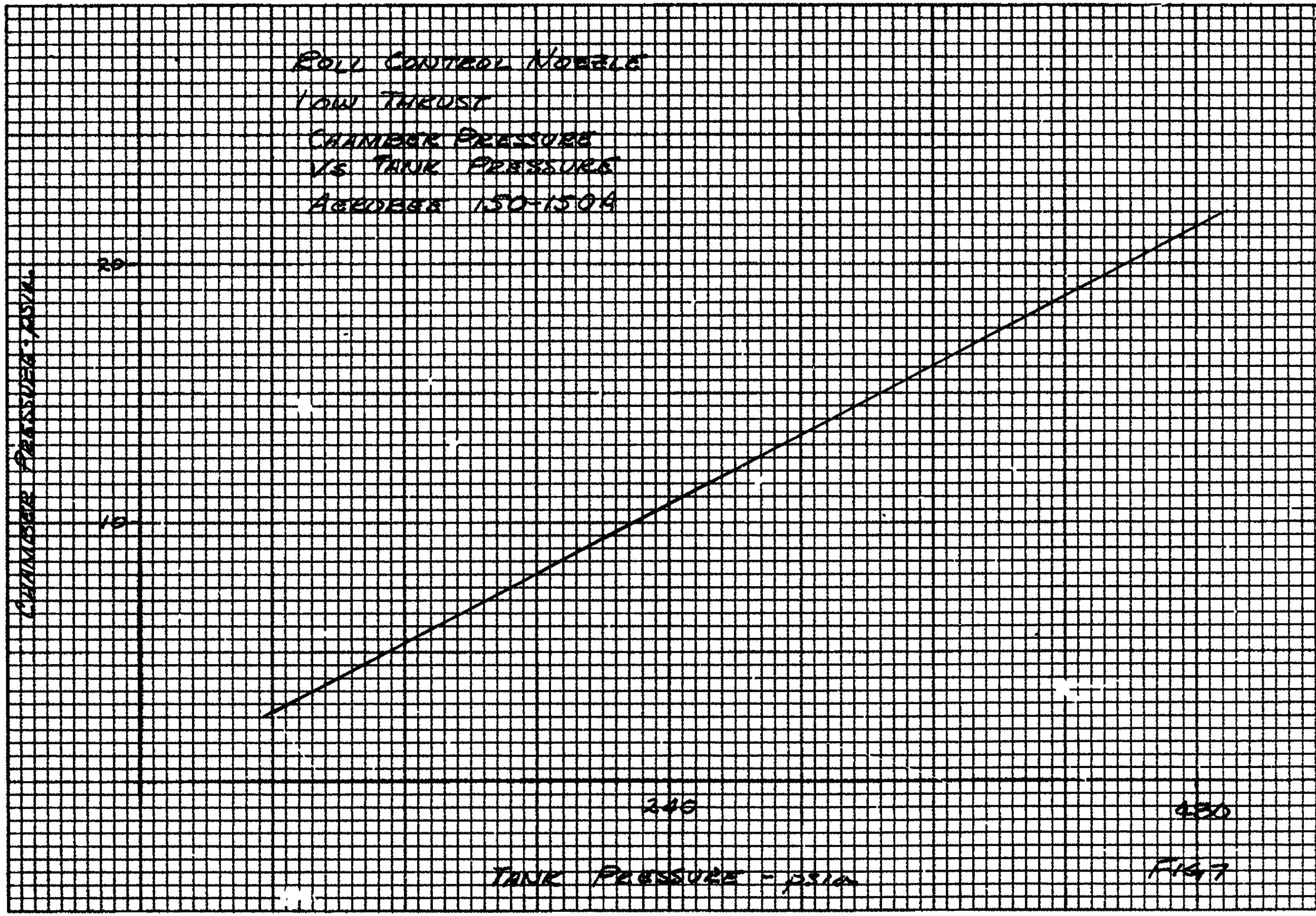


Figure III-7. Roll Control Nozzle Low-Thrust Chamber Pressure Versus Tank Pressure, Aerobee 150-150A

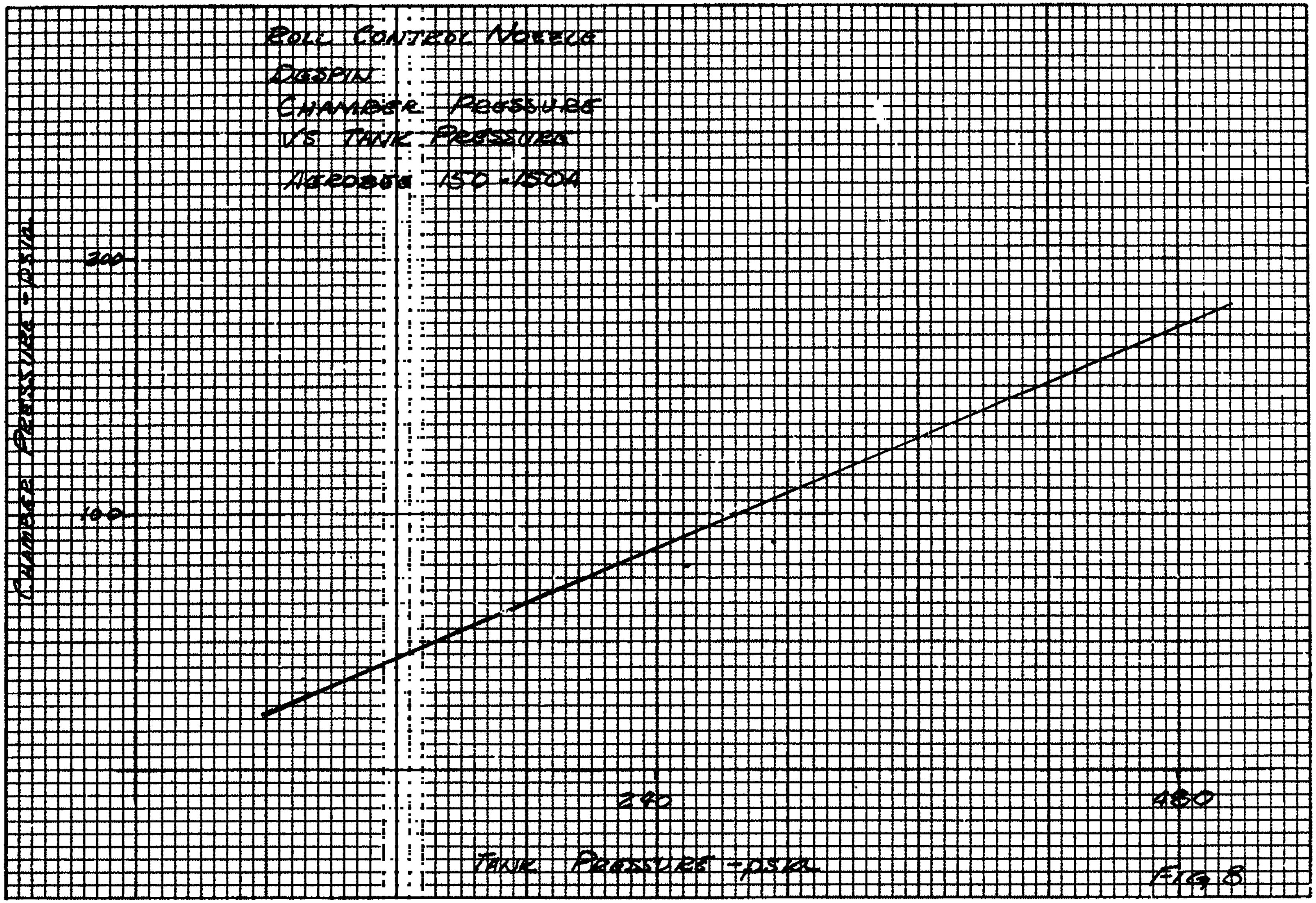


Figure III-8. Roll Control Nozzle Despin Chamber Pressure Versus Tank Pressure, Aerobee 150-150A

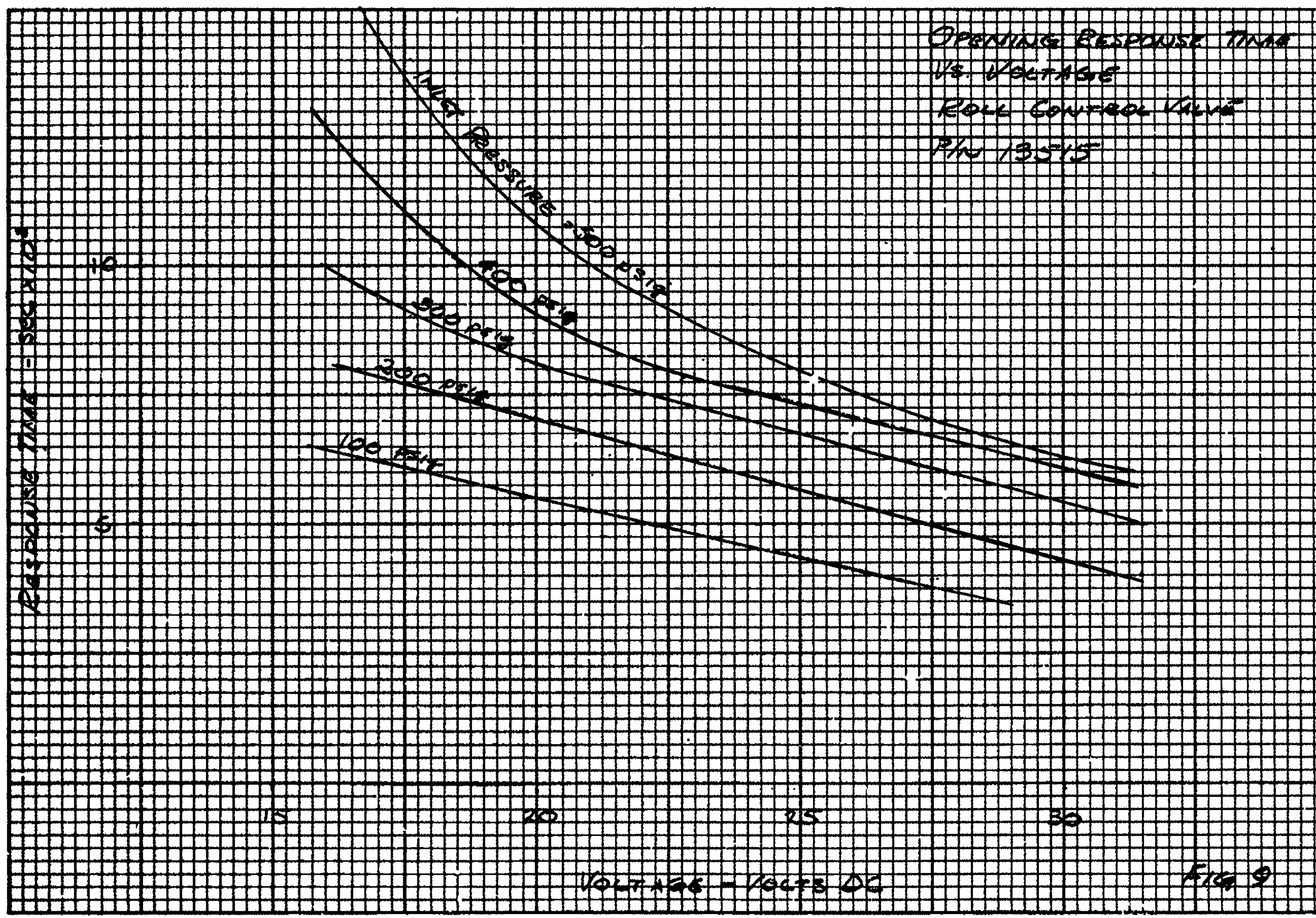


Figure III-9. Opening Response Time Versus Voltage, Roll Control Valve P/N 13515

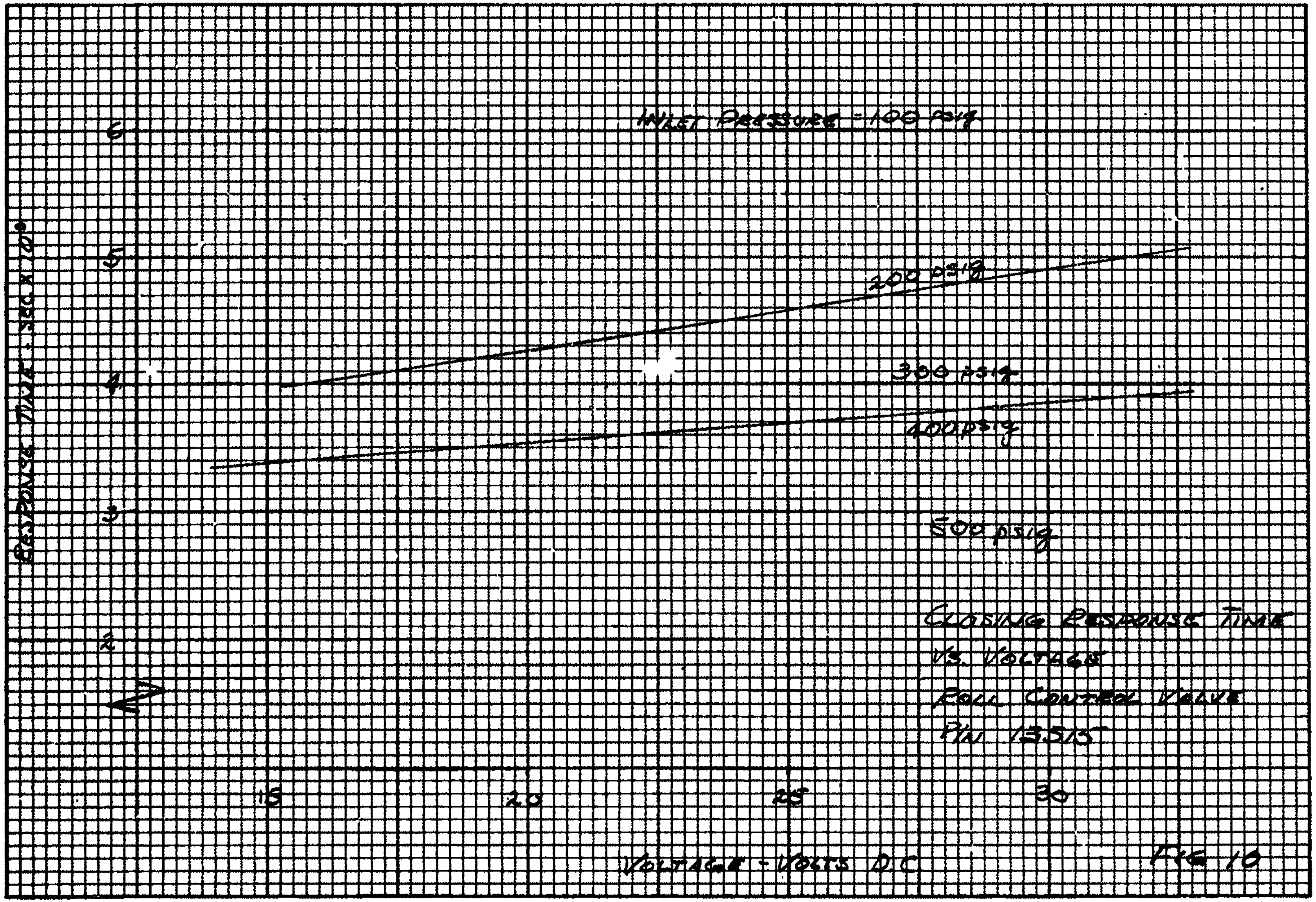


Figure III-10. Closing Response Time Versus Voltage, Roll Control Valve P/N 13515

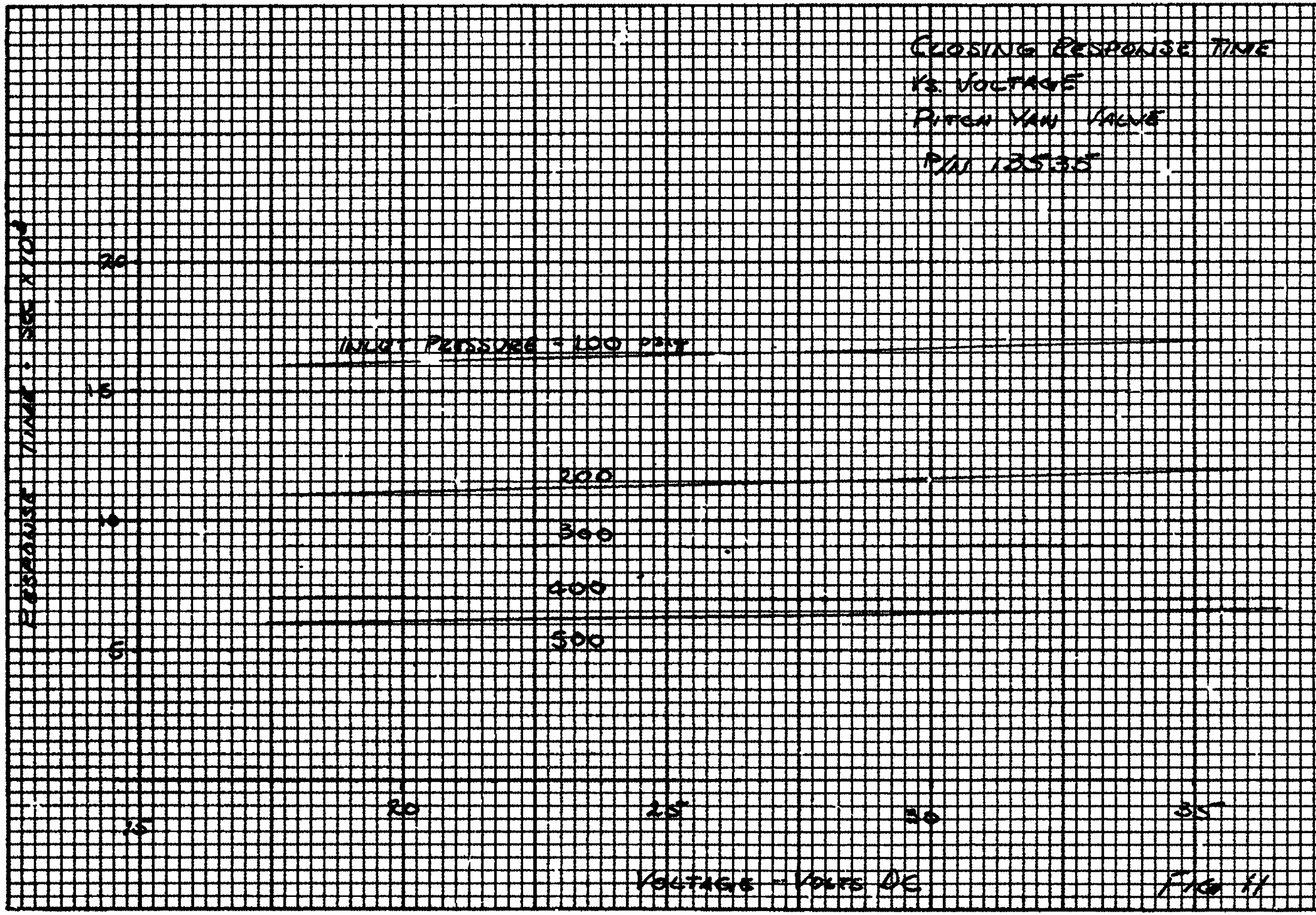


Figure III-11. Closing Response Time Versus Voltage, Pitch/Yaw Valve P/N 13535

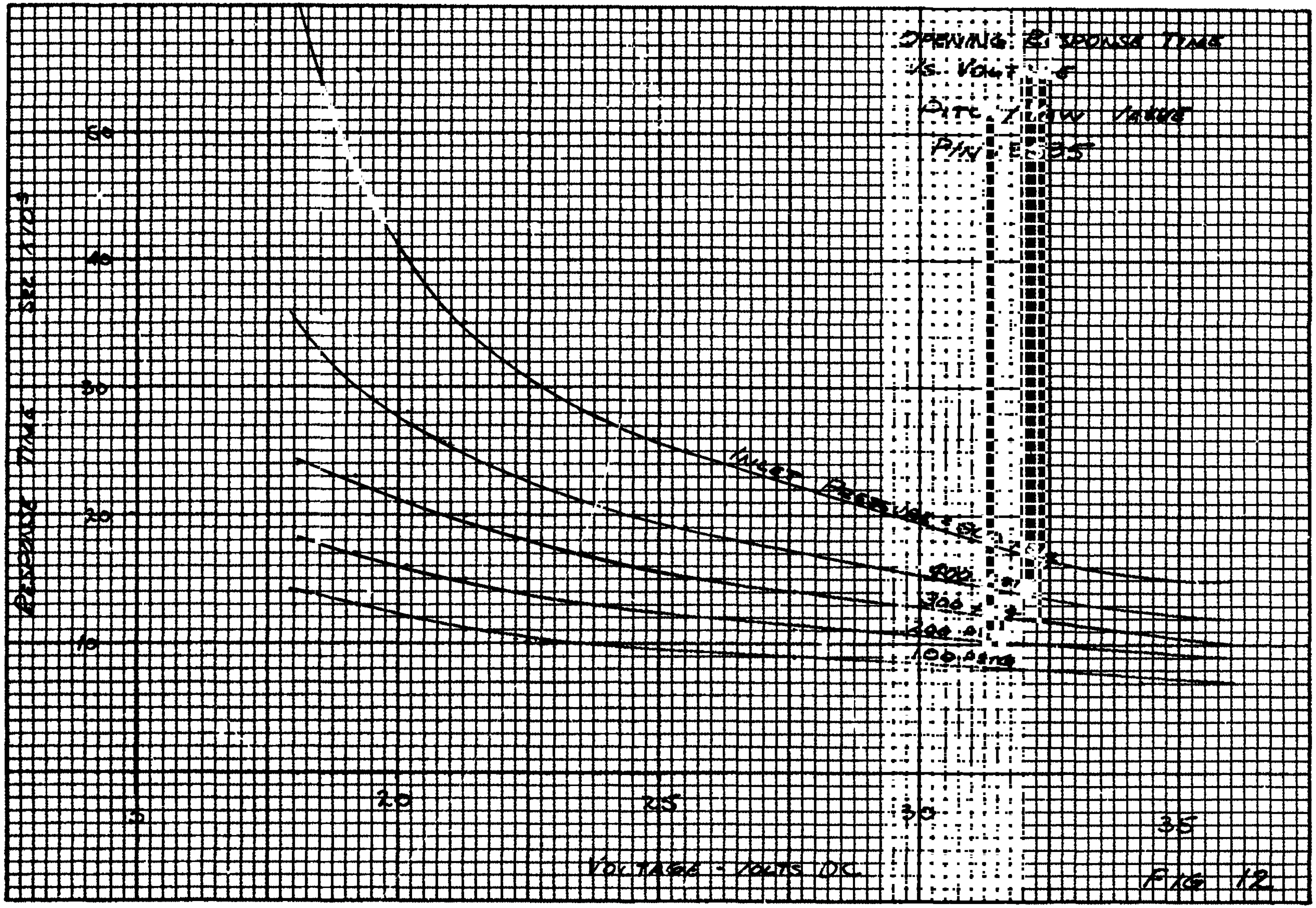


Figure III-12. Opening Response Time Versus Voltage, Pitch/Yaw Valve P/N 13535

Appendix IV

BREADBOARD FACS SUBASSEMBLY AND MODULE TEST DATA

CONTENTS

A. STATIC INVERTER

NO LOAD BENCH MEASUREMENTS

Input Voltage	28	VDC
Input Current	.570	ADC
Output Voltage ØA	25.870	VRMS
Output Voltage ØB	25.960	VRMS
Frequency	399.9	CPS
Phase	91.1	Degrees

SHORT CIRCUIT PROTECTION

Each phase was short circuited independently 5 times for a minimum of 10 seconds each time while monitoring the output. Operation of the inverter was verified after the test.

DEFINITION OF TEST LOADS

No load - open circuit outputs

1/2 load - (each phase) VA = 61.5

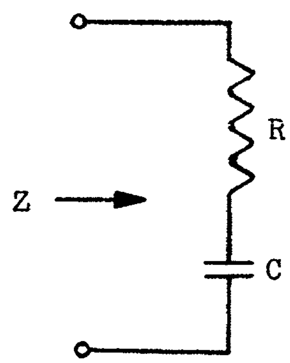
$C = 50\ \mu f$

$X_c = 8\ \Omega$

$R = 7.5\ \Omega$

$Z = 11\ \Omega$

P.F. = .73



Full Load - (each phase) VA = 123

$C = 100\ \mu f$ $Z = 5.5\ \Omega$

$X_c = 4\ \Omega$ P.F.= .73

$R = 3.75\ \Omega$

PERFORMANCE TESTS

Table IV-1 shows the results of the room temperature test performed on the static inverter. Performance data at the temperature extremes of 40°F and 120°F are shown in Tables IV-2 and IV-3.

Table IV-1

ROOM TEMPERATURE TEST - STATIC INVERTER

Parameters Measured	Power Factor = 1.0		Power Factor = 0.73	
	1/2 Load	Full Load	1/2 Load	Full Load
Input Voltage at +28 VDC				
Input Current (ADC)	10.0	20.0	10.0	19.0
Output Current (ARMS) ØA	[illegible].5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.1	2.4	4.8
Output Voltage ØA - VRMS	25.880	26.070	25.940	26.240
Output Voltage ØB - VRMS	26.030	26.120	26.197	26.750
Total Harmonic Distortion ØA	1.3	1.4	1.56	1.7
Total Harmonic Distortion ØB	.8	1.3	1.0	1.4
Frequency	399.9	399.9	399.9	400.1
Phase	90.9	90.0	90.1	90.0
Input Voltage at +24 VDC				
Input Current (ADC)	11.0	21.0	10.2	19.2
Output Current (ARMS) ØA	2.5	5.1	2.4	4.[illegible]
Output Current (ARMS) ØB	2.5	5.1	2.4	4.8
Output Voltage ØA - VRMS	25.870	26.104	25.940	2[illegible].170
Output Voltage ØB - VRMS	25.890	25.840	26.2[illegible]0	26.650
Total Harmonic Distortion ØA	1.2	1.25	1.5	1.72
Total Harmonic Distortion ØB	.76	1.3	.9	1.35
Frequency	400.0	400.1	400.0	400.0
Phase	90.9	90.0	90.1	90.0
Input Voltage at +34 VDC				
Input Current (ADC)	11.0	21.0	10.2	19.2
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.1	2.4	4.8
Output Voltage ØA - VRMS	25.830	26.130	25.850	26.150
Output Voltage ØB - VRMS	25.970	25.940	26.180	26.620
Total Harmonic Distortion ØA	1.11	1.12	1.25	1.4
Total Harmonic Distortion ØB	.710	1.21	.750	1.20
Frequency	400.1	400.[illegible]	400.3	400.2
Phase	90.9	90.0	90.1	90.0

Table IV-2

40°F TEMPERATURE TEST - STATIC INVERTER

Parameters Measured	Power Factor = 1.0		Power Factor = 0.73	
	1/2 Load	Full Load	1/2 Load	Full Load
Input Voltage at +28 VDC				
Input Current (ADC)	10.1	20.5	10.0	19.0
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.1	2.4	4.8
Output Voltage ØA - VRMS	25.890	26.049	25.969	26.190
Output Voltage ØB - VRMS	26.010	26.260	26.310	26.840
Total Harmonic Distortion ØA	1.45	1.6	1.69	1.8
Total Harmonic Distortion ØB	.9	1.3	1.1	1.3
Frequency	399.6	399.6	399.7	399.8
Phase	91.0	90.9	91.0	90.9
Input Voltage at +24 VDC				
Input Current (ADC)	11.0	20.3	10.1	19.1
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.1	2.4	4.8
Output Voltage ØA - VRMS	25.910	26.050	25.960	26.220
Output Voltage ØB - VRMS	25.930	26.100	26.280	26.710
Total Harmonic Distortion ØA	1.42	1.5	1.5	1.7
Total Harmonic Distortion ØB	.9	1.25	1.0	1.29
Frequency	399.8	399.9	399.9	399.9
Phase	91.0	90.9	91.0	90.5
Input Voltage at +34 VDC				
Input Current (ADC)	11.0	20.9	10.0	19.0
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.1	2.4	4.8
Output Voltage ØA - VRMS	25.890	26.080	25.850	26.140
Output Voltage ØB - VRMS	26.036	26.300	26.270	26.810
Total Harmonic Distortion ØA	1.3	1.3	1.38	1.4
Total Harmonic Distortion ØB	.8	1.11	.83	1.25
Frequency	399.9	400.0	400.0	400.0
Phase	91.1	90.9	91.0	90.9

Table IV-3

120°F TEMPERATURE TEST -- STATIC INVERTER

Parameters Measured	Power Factor = 1.0		Power Factor = 0.73	
	1/2 Load	Full Load	1/2 Load	Full Load
Input Voltage at +28 VDC				
Input Current (ADC)	10.1	20.0	10.0	19.0
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.0	2.4	4.8
Output Voltage ØA - VRMS	26.010	26.030	26.000	26.270
Output Voltage ØB - VRMS	25.970	25.990	26.120	26.380
Total Harmonic Distortion ØA	1.2	1.59	1.25	1.40
Total Harmonic Distortion ØB	.86	1.35	1.0	1.40
Frequency	400.1	400.2	400.2	400.3
Phase	91.0	91.0	91.0	90.0
Input Voltage at +24 VDC				
Input Current (ADC)	11.0	21.0	10.1	19.0
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.0	2.4	4.8
Output Voltage ØA - VRMS	25.920	26.080	25.780	26.230
Output Voltage ØB - VRMS	25.670	25.650	26.050	26.650
Total Harmonic Distortion ØA	1.1	1.05	.82	1.01
Total Harmonic Distortion ØB	.9	1.2	1.0	1.01
Frequency	400.2	400.1	400.1	400.2
Phase	91.1	91.0	91.0	90.0
Input Voltage at +34 VDC				
Input Current (ADC)	11.0	20.0	10.1	19.0
Output Current (ARMS) ØA	2.5	5.1	2.4	4.8
Output Current (ARMS) ØB	2.5	5.0	2.4	4.8
Output Voltage ØA - VRMS	25.870	26.030	25.920	26.180
Output Voltage ØB - VRMS	25.740	25.330	26.030	26.270
Total Harmonic Distortion ØA	.98	1.4	.94	.94
Total Harmonic Distortion ØB	.8	1.30	.74	1.0
Frequency	400.1	400.2	400.0	400.0
Phase	91.0	91.0	91.0	90.0

FOUR HOUR STABILITY TEST

The static inverter was run continuously for four hours with a resistive half load. The stability of each output phase is shown below:

Time (Minutes)	EØA (VRMS)	EØB (VRMS)
0	25.930	26.130
15	25.900	25.980
30	25.900	25.910
45	25.900	25.900
60	25.910	25.890
75	25.900	25.894
90	25.884	25.894
105	25.894	25.884
120	25.909	25.884
135	25.909	25.910
150	25.910	25.898
165	25.910	25.890
180	25.900	25.890
195	25.900	25.880
210	25.910	25.880
225	25.910	25.870
240	25.900	25.900

WORST CASE CONFIDENCE TEST

The static inverter was mounted in the center of a 20-inch-square, 3/8-inch-thick aluminum plate heat sink and run with a full load (P.F. = 0.73) for 30 minutes. Thermocouples were attached to one of the STC 1726 power transistor studs, to the corner of the transistor mounting block, and to the heat sink plate (5 inches from the transistor mounting block). Figure IV-1 shows the results of this severe test.

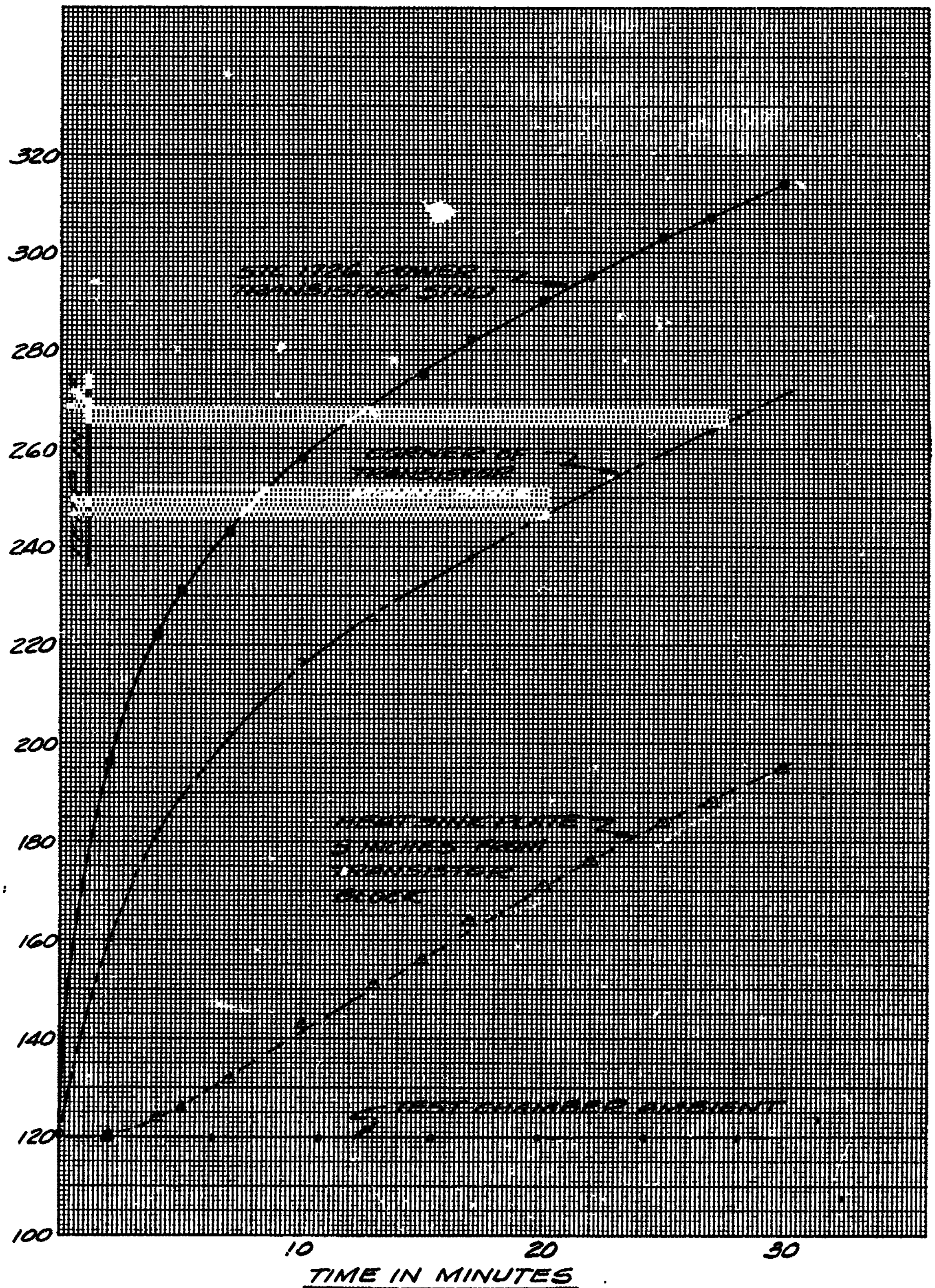


Figure IV-1. Worst Case Confidence Test, Static Inverter

B. DC POWER SUPPLY

NO LOAD BENCH MEASUREMENTS

+15 VDC Supply

Input Voltage	+28 VDC
Input Current	10.2 MADC
Output Voltage	15.008 VDC
Output Current	0 ADC

-15 VDC Supply

Input Voltage	26.020 VRMS
Input Current	90 MARMS
Output Voltage	15.045 VDC
Output Current	0 ADC
Ripple	.25 MVRMS

1/2 LOAD BENCH SETTINGS

+15 VDC Supply

Input Voltage	28 VDC
Output Voltage	14.999 VDC

-15 VDC Supply

Input Voltage	25.983 VRMS
Output Voltage	15.023 VDC

SHORT CIRCUIT PROTECTION

Each output was short circuited independently five times for a minimum of 10 seconds each time while monitoring the output. Operation of both supplies was verified after the tests.

DEFINITION OF TEST LOADS

No Load - open circuit outputs

1/2 Load - (each output) 5.65 watts

$$R_L = \frac{15V}{.375A} = 40\ \Omega$$

Full Load - (each output) 11.3 watts

$$R_L = \frac{15V}{.75A} = 20\ \Omega$$

PERFORMANCE TESTS

Table IV-4 shows the results of the room temperature test performed on the FACS DC power supply. Performance data at the temperature extremes of 40°F and 120°F are shown in Tables IV-5 and IV-6.

FOUR HOUR STABILITY TEST

The DC power supply was run continuously for four hours with a resistive half load. The stability of each output is shown below.

Time (Minutes)	$+E_{Out}$ (VDC)	$-E_{Out}$ (VDC)
0	15.006	15.037
15	15.005	15.036
30	15.005	15.036
60	15.006	15.033
90	15.005	15.034
120	15.006	15.035
150	15.006	15.035
180	15.006	15.035
210	15.006	15.035
240	15.006	15.034

Table IV-4

ROOM TEMPERATURE TEST - DC POWER SUPPLY

Parameters	1/2 Load	Full Load
+15 VDC Supply		
Input Voltage (VDC)	28	28
Input Current (ADC)	.380	.760
Output Voltage (VDC)	14.999	14.996
Output Current (ADC)	.370	.750
Input Voltage	24	24
Input Current	.380	.760
Output Voltage	14.997	14.994
Output Current	.370	.750
Input Voltage	34	34
Input Current	.380	.760
Output Voltage	[illegible]002	14.999
Output Current	.370	.750
-15 VDC Supply		
Input Voltage (VRMS)	26	26
Input Current (ARMS)	.630	1.17
Output Voltage (VDC)	15.026	15.021
Output Current (ADC)	.370	.750
Ripple (VRMS)	.57	.84
Input Voltage	25.5	25.5
Input Current	.630	1.17
Output Voltage	15.025	15.020
Output Current	.370	.750
Ripple	.57	.85
Input Voltage	26.5	26.5
Input Current.	.630	1.17
Output Voltage	15.025	15.020
Output Current	.370	.750
Ripple	.57	.850

Table IV-5

40^{o}F TEMPERATURE TEST - DC POWER SUPPLY

Parameters	1/2 Load	Full Load
+15 VDC Supply		
Input (VDC) Input Current (ADC) Output Voltage (VDC) Output Current (ADC)	28 .380 15.001 .370	28 .760 14.998 .750
Input Voltage Input Current Output Voltage Output Current	24 .380 14.999 .370	24 .760 14.996 .750
Input Voltage Input Current Output Voltage Output Current	34 .380 15.004 .370	34 .760 15.001 .750
-15 VDC Supply		
Input Voltage (VRMS) Input Current (ARMS) Output Voltage (VDC) Output Current (ADC) Ripple (VRMS)	26 .635 15.034 .370 .61	26 1.17 15.029 .750 .94
Input Voltage Input Current Output Voltage Output Current Ripple	25.5 .635 15.033 .370 .63	25.5 1.17 15.028 .750 .94
Input Voltage Input Current Output Voltage Output Current Ripple	26.5 .635 15.032 .370 1.2	26.5 1.17 15.027 .750 1.45

Table IV-6

120°F TEMPERATURE TEST - DC POWER SUPPLY

Parameters	1/2 Load	Full Load
+15 VDC Supply		
Input (VDC) Input Current (ADC) Output Voltage (VDC) Output Current (ADC)	28 .380 14.997 .370	28 .760 14.994 .750
Input Voltage Input Current Output Voltage Output Current	24 .380 14.995 .370	24 .760 14.992 .750
Input Voltage Input Current Output Voltage Output Current	34 .380 14.999 .370	34 .760 14.996 .750
-15 VDC Supply		
Input Voltage (VRMS) Input Current (ARMS) Output Voltage (VDC) Output Current (ADC) Ripple (VRMS)	26 .630 15.019 .370 .62	26 1.17 15.014 .750 .940
Input Voltage Input Current Output Voltage Output Current Ripple	25.5 .630 15.018 .370 .61	25.5 1.17 15.013 .750 .93
Input Voltage Input Current Output Voltage Output Current Ripple	26.5 .630 15.018 .370 .59	26.5 1.17 15.013 .750 .88

C. PROGRAMMER

GENERAL

The program shown below was used for the programmer performance test. Resistors were used to simulate gyro torquer motor windings. All connector pin numbers are referenced to Figure I-3 in Appendix I.

Ledex Position	Hold Time		Maneuver		
	Seconds	Note	Axis	Approximate Magnitude	Direction
12			Start Position		
1	0	T_o	Yaw	75°	CCW
2	65	T_1	Yaw	30°	CCW
3	0	T_o	Yaw	30°	CW
4	65	T_2	Pitch	15°	CCW
5	0	T_o	Pitch	15°	CW
6	65	T_3	Roll	30°	CW
7	0	T_o	Roll	30°	CCW
8	65	T_4	Pitch	30°	CW
9	0	T_o	Pitch	30°	CCW
10	0	T_o	Yaw	30°	CW
11					

ROOM TEMPERATURE TEST

1. Program Position Monitor

   a. 5.01 VDC was applied to P11-17.

   b. The ledex and record program position output (P10-3) voltage was advanced for all positions. The program position output is shown below.

Ledex Position	Output (VDC)	Step Change
12	0	
1	5.010	5.010
2	4.557	0.453
3	4.103	0.454
4	3.649	0.454
5	3.196	0.453
6	2.728	0.468
7	2.273	0.455
8	1.818	0.455
9	1.364	0.454
10	0.911	0.453
11	0.455	0.456
12	0	0.455

2. <u>"AND" Gates</u>

The results of tests run on "AND" No. 1, No. 2, and No. 3 (all produce the the same results) are shown below.

Input Voltage (VDC)	Supply Voltage at (VDC)		
	+24	+28	+34
Minimum to fire	+7.5	+7.5	+7.5
Normal-True	+15	+15	+15
Normal-False Maximum	+0.45	+0.45	+0.45

3. Flip-Flop Triggering

a. Flip-Flop No. 1

The minimum voltage (applied to P10-6) to change transistor Q10 from the OFF state to the ON state is +3.4 VDC. The normal voltages applied are zero or +24 to +34 VDC.

The voltages required at the collector of transistor Q11 to change transistor Q11 from the ON state to the OFF state is +6 VDC. The normal collector voltage of Q11 is either V_{CE}-sat (maximum of +0.45 VDC) or +15 VDC.

b. Flip-Flop No. 2

The minimum voltage (applied to P10-6) to change transistor Q16 from the OFF state to the ON state is 3.6 VDC. The normal voltages applied are zero or +24 to +34 VDC.

The voltages required at the collector of transistor Q15 to change transistor Q16 from the ON state to the OFF state is +6 VDC. The normal collector voltage of Q15 is either V_{CE}-sat (maximum of +0.45 VDC) or +15 VDC.

The minimum voltage applied to the cathodeof CR36 required to change Q16 from the OFF state to the ON state is +6 VDC. The normal trigger pulse from the hold time delay circuit is a 12-volt decaying exponential of about two-milliseconds duration. Except for the trigger pulse, zero volts is applied to CR36.

c. Flip-Flop No. 3

The minimum voltage (applied to P10-6) to change transistor Q18 from the OFF state to the ON state is 3.8 VDC. The normal voltages applied are zero or +24 to +34 VDC.

The minimum voltage applied to the cathode of CR36 required to change Q17 from the OFF state to the ON state is 5.9 VDC. The normal trigger pulse from the hold time delay circuit is a 12-volt decaying exponential of about two-milliseconds duration. Except for the trigger pulse, zero volts is applied to CR36.

The minimum voltage applied to the junction of CR41 and R72 to change transistor Q18 from the OFF state to the ON state is +3.3 VDC. The normal voltages applied are zero and +15 VDC.

The minimum voltage applied to the junction of CR40 and R72 to change transistor Q18 from the OFF state to the ON state is +1.0 VDC. The normal voltage is applied through a 10K resistor from test point No. 4 in the programmer trigger. The normal voltages at test point No. 4 are -0.5 and +5 VDC.

TEMPERATURE TESTS

By applying +28 VDC to P10-2, the programmer self sequences itself through a complete program. This method was used to check the overall programmer logic performance. Test runs were made at temperatures of +40°F, room temperature, and +120°F at main supply voltages of +24, +28, and +34 VDC. The primary programmer outputs were recorded to check the sequential logic functions of the programmer.

The inner gimbal compensation network was grossly checked to see that torquing time was a function of the input angular signal. The relation used was $t = t_o \cos \theta$, where t_o = torquing time with $\theta = 0$.

1. Coast Time Delay

   The results of the temperature tests on the coast time delay are shown below. The time delay was set for a nominal 9 seconds.

Supply Voltage (VDC)	Temperature		
	+40°F	Room	+120°F
+24	9.3	9.3	9.4
+28	9.2	9.2	9.2
+34	9.0	9.0	9.1

2. Hold Time Delay

   a. A nominal 65 seconds was used for each of four test time delays.

   b. The hold time delay circuit resets from its maximum output of 6.5 VDC to zero in less than 5 milliseconds.

   c. The worst case time delay variation for all supply voltages and temperatures was ± 2.1%. The variation at constant temperature was less than 1.0%.

   d. The results of the temperature test on the hold time delay are shown below.

Time Delay	Supply Voltage	Temperature		
		+40°F	Room Temp	+120°F
T_1	24 28 34	65.9 65.7-66.2 66.1	64.9 64.6-64.7 65.0	64.8 64.4-64.7 64.7
T_2	24 28 34	66.3 66.3-66.8 66.5	65.1 64.8-65.0 65.2	65.0 64.2-64.9 64.3
T_3	24 28 34	66.0 66.2-66.6 66.4	65.2 64.8-65.1 65.3	65.0 64.3-64.9 64.5
T_4	24 28 34	66.5 66.5-66.9 66.7	65.6 64.9-65.3 65.6	65.4 64.6-65.3 65.3
T_o	All	0.5	0.5	0.5

D. IACS CONTROL ELECTRONICS

GENERAL

All tests on this subassembly were performed under ambient conditions and at rated supply voltages unless otherwise specified. All AC test signals and angular measurements were obtained with a position gyro synchro index head. Connector pin numbers refer to Figure I-5 in Appendix I.

ROOM TEMPERATURE TESTS (NOTE - Resistor loads were used to simulate valves.)

Roll Capture

Input	Apply AC test signal at P12-34 (demod input)
Output	Monitor half trigger output at P12-2
Capture	Measured input angle: $1^{\circ}30'$
Input	Apply +15 VDC at P12-6 (AND roll capture)
Output	Monitor P13-32 (roll capture)
Jumper	P12-28 to P12-29

Check that relay K3 locks up properly when +15 VDC at P12-6 is removed

Roll Position

Ground	Rate channel input at P12-19
Input	Apply AC test signal at P12-34 (demod input)
Output	Monitor P12-14 (CCW valve) and P12-15 (CW valve)
CW	Measured switch point: 14.2 arc min (in-phase input)
CCW	Measured switch point: 15.7 arc min (out-of-phase input)
Output	Monitor output at P13-16 (roll position demod)
Check	Operation satisfactory

Apply +28V to P12-7 (arm roll). Observe continuity between P12-15 and P12-16 when K7 is activated.

Roll Rate

Ground	Position channel input at P12-34
Input	Apply AC test signal at P12-19 (buffer input)
Output	Monitor P12-14 (CCW valve) and P12-15 (CW valve)

K3 Deactivated:

CW	6.4 arc min (in-phase input)
CCW	6.75 arc min (out-of-phase input)
K3 Activated: -	by applying +15 VDC to P12-6.
CW	11.7 arc min
CCW	12.5 arc min

Despin Transfer Relay

Check that relay (K7) is energized and self-latched by the roll CCW valve driver.

Pitch Capture

Jumper	P12-22 to P12-23 (high level)
Input	Apply AC test signal at P12-33 (demod input)
Output	Monitor P12-4 (pitch capture signal)
Capture	Measured input angle: $1^{\circ}54'$
Jumper	P12-23 to P12-24 (low level)
Capture	Measured input angle: 22 arc min)
Output	Monitor P13-33 (pitch capture)
Check	Operation satisfactory

Pitch Position

Ground	Rate channel input at P12-20
Apply	+28 VDC to P12-8 (error test)
Input	Apply AC test signal at P12-33 (demod input)
Output	Monitor P12-12 (CCW valve) and P12-13 (CW valve)
CW	Measured switch point 15 arc min (in-phase input)
CCW	Measured switch point 15.2 arc min (out-of-phase input)
Output	Monitor P13-18 (pitch position demod): check satisfactory
Output	Monitor P13-36 (pitch position DC): check satisfactory
Remove	+28 VDC from P12-8: check satisfactory
Apply	+15 VDC to P12-6: check satisfactory
Check	Observe continuity from P12-31 to ground
Check	Control of valve driver by K6: check satisfactory

Pitch Rate

Ground	P12-33 (position channel input)
Apply	+28 VDC to P12-8 (error test)
Input	Apply AC test signal at P12-20 (buffer input)
Output	Monitor P12-12 (CCW valve) and P12-13 (CW valve)

K1 Deactivated: Low K_R

CW	9.0 arc min (in-phase input)
CCW	8.2 arc min (out-of-phase input)

K1 Activated: (400 cps signal to P12-23) High K_R

CW	5.5 arc min
CCW	1.6 arc min

Output	Monitor P13-21 (pitch rate demod): check satisfactory

Yaw Capture

Jumper	P12-25 to P12-26 (high level)
Input	Apply AC test signal at P12-32 (demod input)
Output	Monitor P12-5 (yaw capture signal)
Capture	Measured input angle - 2°
Jumper	P12-26 to P12-27 (low level)
Capture	Measured input angle 24 arc min
Output	Monitor P13-34 (yaw capture)
Check	Operation satisfactory

Yaw Position

Ground	Rate channel input at P12-21
Apply	+28V to P12-8 (error test)
Input	Apply AC test signal at P12-32 (demod input)
Output	Monitor P12-10 (CCW valve) and P12-11 (CW valve)
CW	Measured switch point 15.1 arc min (in-phase input)
CCW	Measured switch point 15.1 arc min (out-of-phase input)
Output	Monitor P13-19 (yaw position demod): check satisfactory
Output	Monitor P13-37 (yaw position DC): check satisfactory

Remove	+28 VDC from P12-8: check satisfactory
Apply	+15V to P12-6: check satisfactory
Apply	+28 VDC to P12-8 (error test) with +28 VDC removed from P13-9
Check	Observe continuity from P13-9 to P13-35
Check	Control of valve drivers by K6: check satisfactory

<u>Yaw Rate</u>

Ground	P12-32 (position channel input)
Apply	+28 VDC to P12-8 (error test)
Input	Apply AC test signal at P12-21 (buffer input)
Output	Monitor P12-10 (CCW valve) and P12-11 (CW valve)

<u>K2 Deactivated</u>: Low K_R

CW	<u>8.8</u> arc min (in-phase input)
CCW	<u>8.6</u> arc min (out-of-phase input)

<u>K2 Activated</u>: (400 cps signal to P12-26)

CW	<u>4.7</u> arc min
CCW	<u>2.7</u> arc min

Output Monitor P13-22 (yaw rate demod): check satisfactory

<u>Slave Roll</u>

Input	Apply AC test signal at P12-35 (demod input)
Apply	+15V to P13-13
Apply	-15V to P13-12
Output	Monitor P12-9 (S.R. null), P12-36 (S.R. tor cont), P12-37 (S.R. tor ref)

Measured Trigger Points:

CW	14.6 arc min (in-phase input)
CCW	14.8 arc min (out-of-phase input)
Apply	+15V to P12-3 (arm S. roll)
Output	Monitor P12-18: check satisfactory

Minimum SCR trigger voltage ≐ 5.5 VDC

Output Monitor P13-17 (demod output): check satisfactory

Buffer Amplifiers (Rate Channels)

Roll Amplifier

Input to P12-19	
Output from Q1	
Dynamic Range	18 VP-P
Input Impedance	11.4K ohms
Output Impedance	46 ohms
Voltage Gain	1

Pitch Amplifier

Input to P12-20	
Output from Q2	
Dynamic Range	15 VP-P
Input Impedance	11.4K ohms
Output Impedance	42 ohms
Voltage Gain	1

Yaw Amplifier

Input to P12-21	
Output from Q3	
Dynamic Range	16 VP-P
Input Impedance	11.4K ohms
Output Impedance	46 ohms
Voltage Gain	1

A summary of the foregoing test data and the results from the temperature tests are included in Table IV-7.

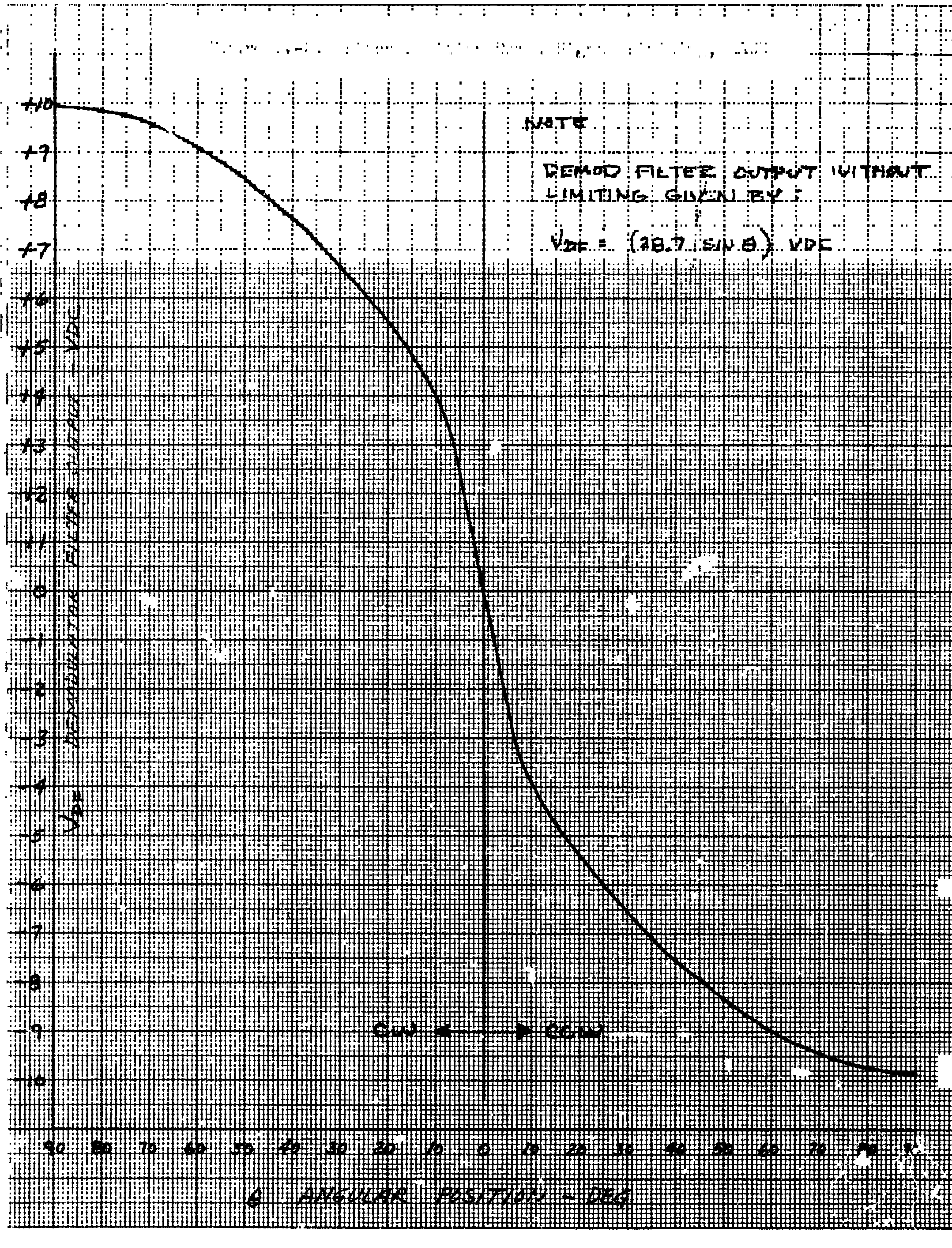
The calibrated effect of the soft-limiting of the output of the pitch and yaw position demodulators is shown in Figures IV-2, IV-3, IV-4 and IV-5. Figure IV-3 is an expanded scale of the region around null ($\pm$ 15^{o}) of Figure IV-2. Figure IV-5 is an expanded scale of Figure IV-4.

Table IV-7

IACS TEMPERATURE TEST SUMMARY

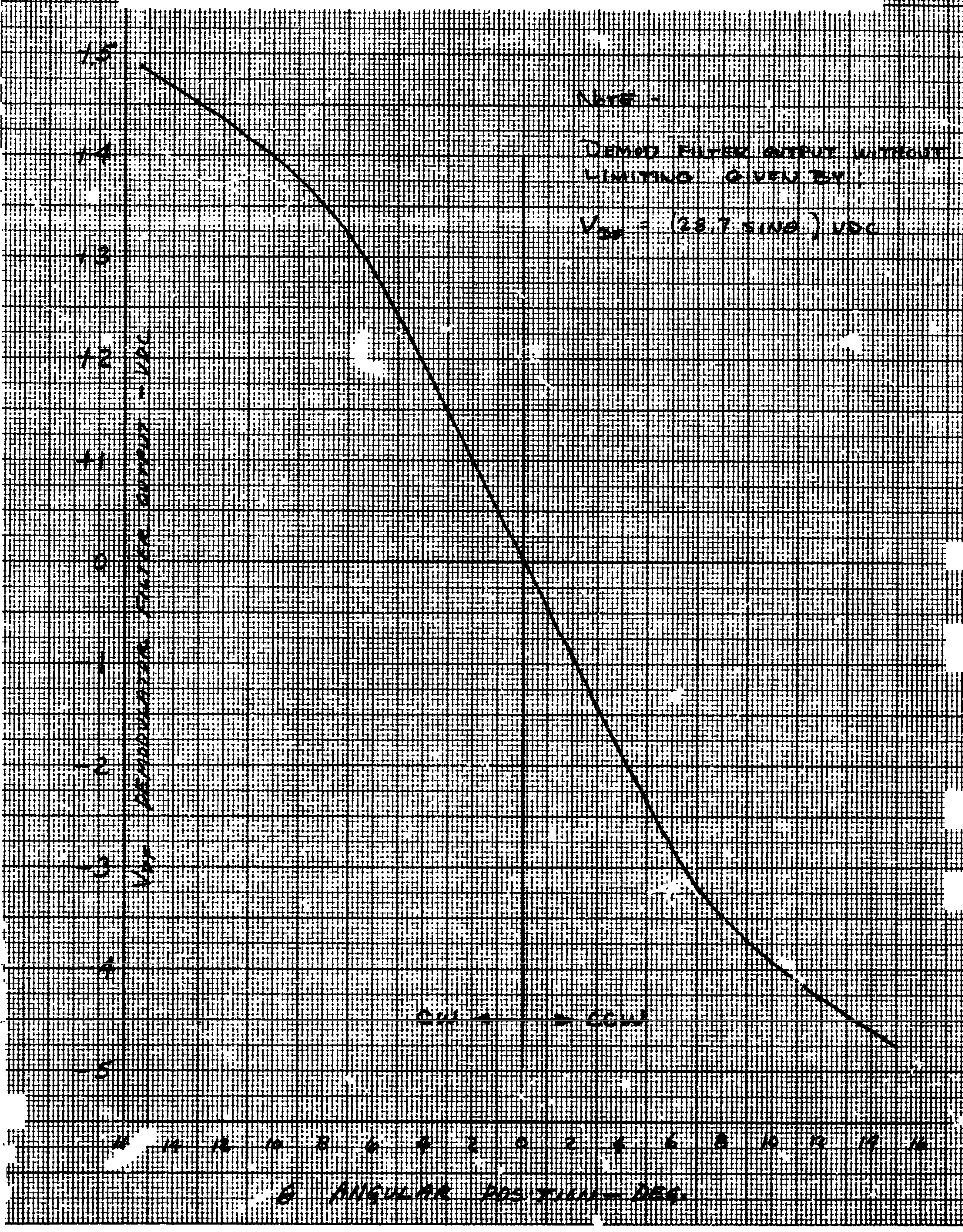
Function		Room Temp	$40^\circ F$	$120^\circ F$
Roll Capture		$1^\circ 30'$	$1^\circ 31.8'$	$1^\circ 24'$
Roll Position	CW	14.2'	15.0'	13.7'
	CCW	15.7'	16.2'	15.8'
Roll Rate* (High K_R)	CW	6.4'	6.3'	6.2'
	CCW	6.75'	6.8'	6.9'
(Low K_R)	CW	11.7'	10.7'	10.3'
	CCW	12.5'	12.6'	12.4'
Pitch Capture	High	$1^\circ 54'$	$2^\circ 5'$	$1^\circ 58.6'$
	Low	22'	23.4'	21.2'
Pitch Position	CW	15.0'	14.9'	15.2'
	CCW	15.2'	15.5'	14.6'
Pitch Rate* (Low K_R)	CW	9.0'	8.3'	8.7'
	CCW	8.2'	8.7'	8.3'
(High K_R)	CW	5.5'	5'	5.2'
	CCW	1.6'	2.2'	2.0'
Yaw Capture	High	2°	$2^\circ 4.8'$	$1^\circ 55'$
	Low	24'	24.6'	21.9'
Yaw Position	CW	15.1'	14.4'	17.2'
	CCW	15.1'	16.0'	11.6'
Yaw Rate* (Low K_R)	CW	8.8'	8.3'	9'
	CCW	8.6'	9.1'	8.1'
(High K_R)	CW	4.7'	4.2'	5.0'
	CCW	2.7'	3.2'	2.4'
Slave Roll	CW	14.6'	14.5'	14.8'
	CCW	14.8'	15.2'	14.6'
SCR - Minimum Trigger Voltage		5.5 VDC	5.6 VDC	5.4 VDC
Buffer Amplifiers				
Z_{in} Roll		11.4K	10.8K	11K
Z_{in} Pitch		11.4K	11K	11K
Z_{in} Yaw		11.4K	11K	11K

*Observed unbalance in switch points attributable to bias voltages at demod outputs. Corrected prior to assembly in FACS system.

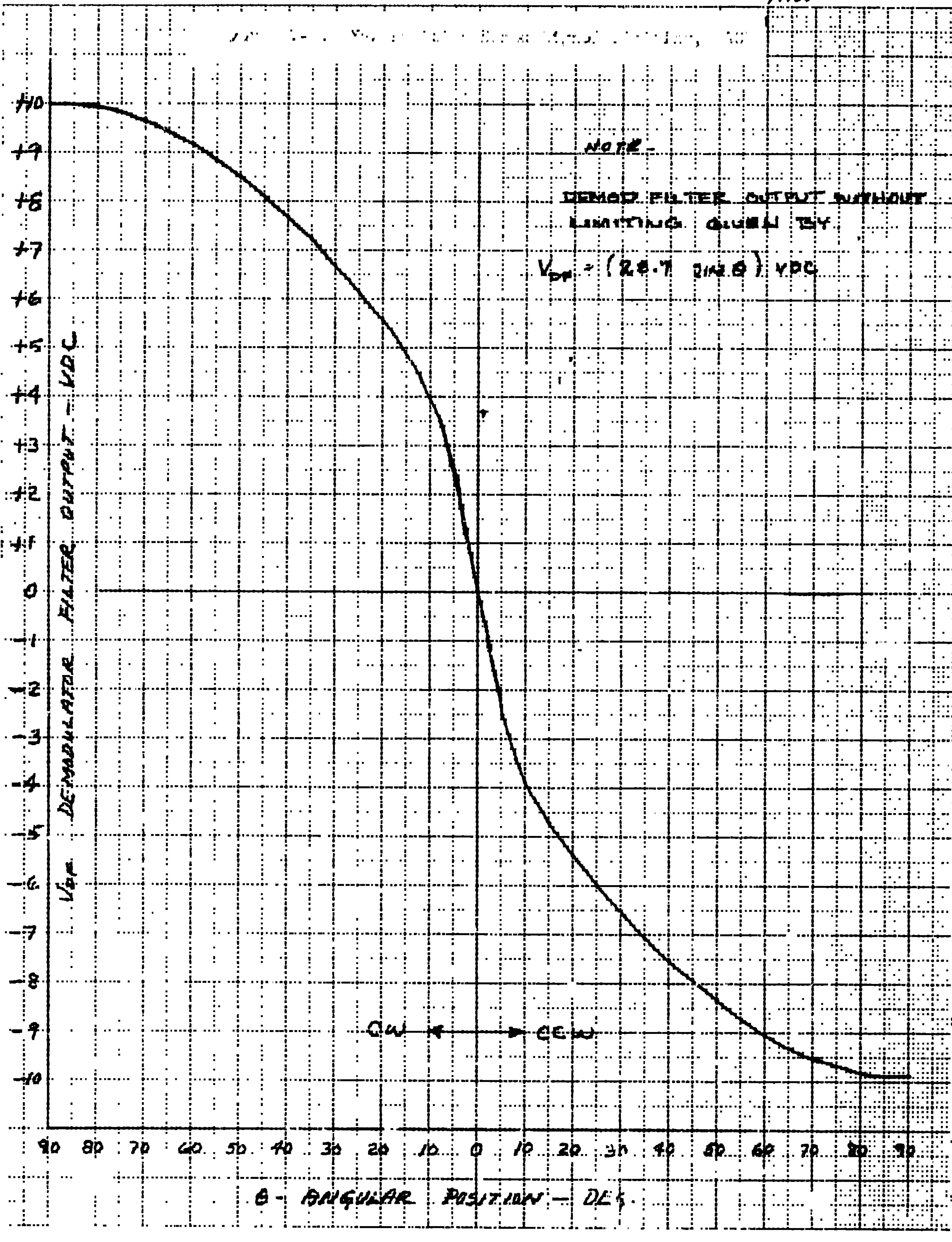


NOTE
DEMOD FILTER OUTPUT WITHOUT LIMITING GIVEN BY :
VDF = (28.7 SIN θ) VDC
CW ← → CCW
+10
+9
+8
+7
+6
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
VDF DEMODULATOR FILTER OUTPUT - VDC
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
θ ANGULAR POSITION - DEG

Figure IV-3. Pitch Position Demod Signal Limiting, IACS (Expanded)

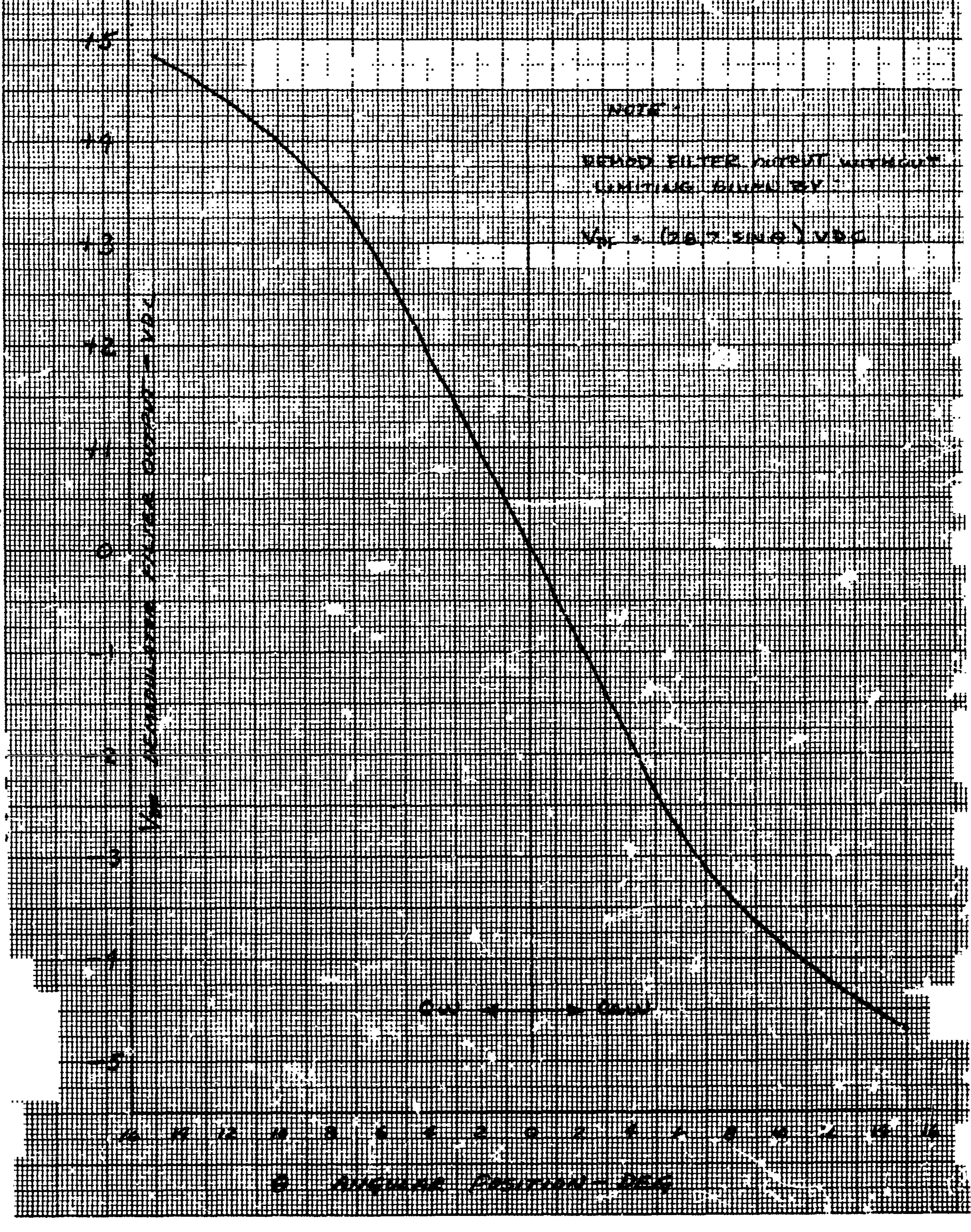


YAW


NOTE -
DEMOD FILTER OUTPUT WITHOUT LIMITING GIVEN BY
V_DF = (28.7 SIN θ) VDC
+10
+9
+8
+7
+6
+5
+4
+3
+2
+1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
V_DF DEMODULATOR FILTER OUTPUT - VDC
CW ← → CCW
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
θ - ANGULAR POSITION - DEG.

YAW

Figure IV-5. Yaw Position Demod Signal Limiting, IACS (Expanded)



E. SACS CONTROL ELECTRONICS

GENERAL

All tests on this subassembly were performed under ambient conditions and at rated supply voltages unless otherwise specified. All AC test signals and angular measurements were obtained with a position gyro synchro index head. Connector pin numbers refer to Figure I-7 in Appendix I.

ROOM TEMPERATURE TESTS (NOTE - Resistor loads were used to simulate valves.)

Control Channel - LT Valves*

Pitch	Input P15-1 (SACS Pitch Pos)	Output P14-21 (CCW)	Output P14-23 (CW)
	-.108 VDC	X	
	+.111 VDC		X

Yaw	Input P15-2 (SACS Yaw Pos)	Output P14-24 (CCW)	Output P14-26 (CW)
	-.106 VDC	X	
	+.114 VDC		X

Gyro Torquing Control Channel (Sensor Input)

Pitch — Ground P14-4 (pitch position - DC)

Apply: +15 VDC to P14-6 to simulate (26V/0)

-15 VDC to P14-7 to simulate (26V/90)

Input P15-1 (SACS Pitch Pos)	Output P15-21 (Pitch Torquer Ref)	Output P15-22 (Pitch Torquer Cont)
+.648 VDC	-15 VDC	+15 VDC (CCW)
-.630 VDC	+15 VDC	-15 VDC (CW)
0	0	0

Yaw — Remove ground from P14-4 and apply to P14-3 (yaw position DC)

Input P15-2 (SACS Yaw Pos)	Output P15-20 (Yaw Torquer Cont)	Output P15-19 (Yaw Torquer Ref)
+.617 VDC	+15 VDC	-15 VDC (CCW)
-.623 VDC	-15 VDC	+15 VDC (CW)
0	0	0

*Phasing reversed prior to installation in system.

Gyro Torquing Control Channel (Position - Demod Input)

Pitch Ground P15-1 (sensor input)

Input P14-4 (Pitch Position DC)	Output P15-21 (Pitch Torquer Ref)	Output P15-22 (Pitch Torquer Cont)
+.0860 VDC	-15 VDC	+15 VDC (CCW)
-.0830 VDC	+15 VDC	-15 VDC (CW)
0	0	0

Yaw Ground P15-2 (sensor input)

Input P14-3 (Yaw Position DC)	Output P15-19 (Yaw Torquer Ref)	Output P15-20 (Yaw Torquer Cont)
+.0805 VDC	-15 VDC	+ 15 VDC (CCW)
-.0807 VDC	+15 VDC	- 15 VDC (CW)
0	0	0

Gyro Synchro Signal-Level Detector

	400 cps input to P14-31 (Pitch Error)	Output P14-33 (Half-Trigger Output)
Pitch	.072 Vrms	X

	400 cps input to P14-32 (Yaw Error)	Output P14-35 (Half Trigger Output)
Yaw	.076 Vrms	X

Time Delay Circuit (Time Delay No. 2)

Pitch TD2P

Time Delay 1.042 seconds

Drop-out 26.7 ms

Yaw TD2Y

Time Delay 1.086 seconds

Drop-out 18.8 ms

SACS Torque Null

Pitch Check - Relay K2 and K3 operation satisfactory

Yaw Check - Relay K7 and K8 operation satisfactory

Valve Switchover

Pitch	Check - Relay K4 operation satisfactory
Yaw	Check - Relay K6 operation satisfactory

Cage Relays

Pitch	Check - Relay K9 operation satisfactory
Yaw	Check - Relay K10 operation satisfactory

Flip-Flop No. 4

Minimum Start Voltage	5.4V
Minimum Stop Voltage	3.0V

(NOTE: Flip-flop trigger circuit later modified to accept SACS stop signal from programmer relay K3)

Time Delay TD1

Time Delay	1.056 seconds
Drop-out	30 ms

Time Delay TD3

Time Delay	0.518 seconds
Drop-out	30 ms

A summary of the foregoing data and the data at the temperature extremes is included in Table IV-8.

Table IV-8

SACS TEMPERATURE TESTS SUMMARY

Function			Room Temp	+40°F	120°F
Control Channel - LT Valves* -	Pitch	CCW	-0.108 VDC	-.112	-.104
		CW	+0.111 VDC	.109	.109
	Yaw	CCW	-0.106 VDC	-.111	-.101
		CW	+0.114 VDC	.114	.117
Gyro Torquing Control - Sensor Input	Pitch	CCW	+0.648 VDC	.633	.663
		CW	-0.630 VDC	-.636	-.611
	Yaw	CCW	+0.617 VDC	.620	.623
		CW	-0.623 VDC	-.623	-.616
Gyro Torquing Control	Pitch	CCW	+0.0860 VDC	.0832	.0867
-Position Demod Input		CW	-0.0830 VDC	-.0865	-.0810
	Yaw	CCW	+0 0805 VDC	.0807	.0811
		CW	-0.0807 VDC	-.0807	-.0811
SACS Level Detector	Pitch		0.072 VRMS	.075	.070
	Yaw		0.076 VRMS	.082	.074
Time Delay No. 2	Pitch	delay	1.042 sec	1.075	.999
		dropout	26.7 ms	24.1	29.7
	Yaw	delay	1.086 sec	1.174	1.046
		dropout	18.8 ms	16.6	21.0
Time Delay No. 1		delay	1.056 sec	1.108	1.022
		dropout	30 ms	25	27
Time Delay No. 3		delay	.518 sec	.542	.503
		dropout	30 ms	25.8	26

*Phasing reversed prior to installation in system.

F. ROLL STABILIZED PLATFORM (RSP)

STE REQUIRED

RSP Test Box P/N 1111788 with modified torquing switches to allow two-phase torquing. STE J4 connector had pins 2, 7, 24 removed.

LAG ANGLE

1. Replace gyros with dummy gyros.
2. Install RSP in temperature conditioning chamber.
3. Use RSP test box to supply amplifier error signal.
4. Obtain error signal amplitude and phase as required in Table IV-9.
5. Convert error signal to equivalent gyro lag angle.

Table IV-9

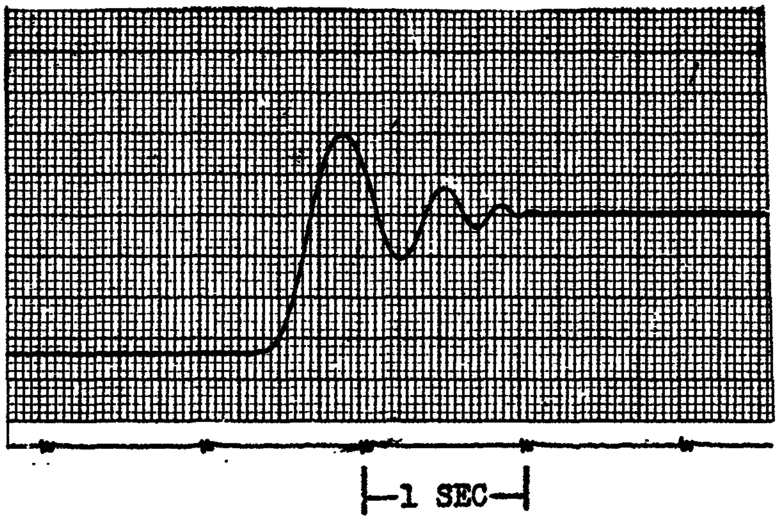
RSP LAG ANGLES

Temp	Direction of Spin	Spin Rate (rps)					
		1		2		3	
		mv	eqv. deg.	v	eqv. deg.	v	deg.
40°F	CW	922.5	4.5	1.85	9	2.76	13.5
	CCW	923.5	4.5	1.85	9	2.76	13.5
72°F	CW	907.5	4.4	1.85	9	2.76	13.5
	CCW	917.5	4.5	1.84	9	2.76	13.5
120°F	CW	917.5	4.5	1.83	9	2.76	13.5
	CCW	905.0	4.4	1.83	9	2.76	13.5

TRANSIENT RESPONSE

1. Manually offset the platform 17°.
2. Release platform and record the settling time on a Sanborn recorder.
3. Perform test in both CW and CCW direction.
4. Test results are shown in Figure IV-6.

CW RECORDER SPEED 20 MM/SEC



CCW

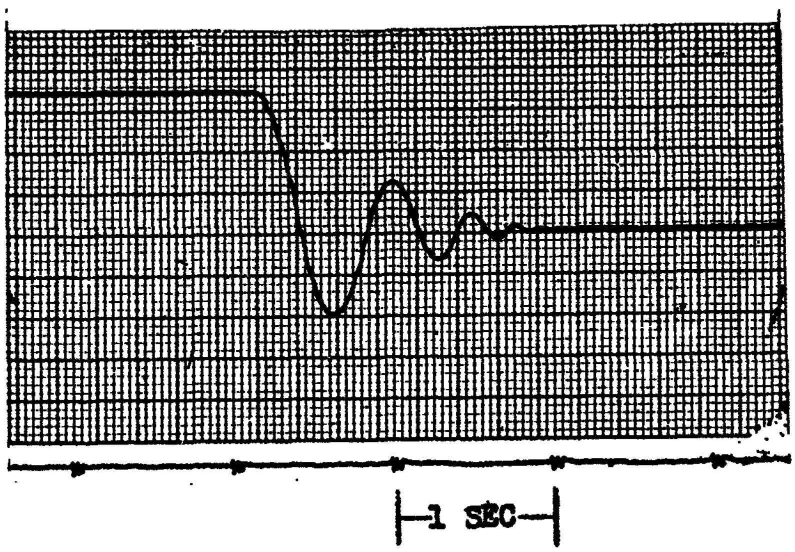


Figure IV-6. Transient Response Test

STATIC DRIFT TESTS

1. Replace the gyros in the RSP.
2. Remove the locking pin from the RSP and apply AC power to RSP.
3. Insert the locking pin and torque all gimbals until they are caged.
4. At the start of each individual drift test, torque the subject gimbal to null. Record the required data in Table IV-10. Use the voltmeter for magnitude and the oscilloscope for phase.

Table IV-10

STATIC DRIFT - RSP

Channel	Null		1 Min			2 Min			3 Min			Phase
	mv	deg	mv	deg	$\frac{deg}{min}$	mv	deg	$\frac{deg}{min}$	mv	deg	$\frac{deg}{min}$	
Roll	3.2	.016	13.0	.063	.063	15.1	.074	.037	15.2	.074	.025	Out
Pitch	3.2	.016	10.0	.049	.049	12.7	.062	.031	17.0	.083	.028	Out
Yaw	6.0	.029	15.8	.077	.077	16.0	.078	.039	16.4	.08	.027	In
S. Roll	6.0	.029	18.8	.092	.092	19.2	.094	.047	20.0	.098	.033	Out

NOTE: 1. Use nominal scale factor of 205 mv/deg.

2. Drift $\left(\frac{deg}{min}\right) = \frac{deg}{\Delta \text{ time}}$ where Δ time = 1, 2, 3 min.

TORQUING RATE

1. These tests are to be performed at 26 VAC on both control and reference phases.
2. Bring gyros up to speed and insert locking pin.
3. Torque gyros to null and follow test sequence in Table IV-11. Re-null each gimbal immediately prior to torquing test. Repeat test sequence 3 times with 10 min wait between each run.
4. For nominal inner gimbal torquing rate, see equation below:

$$\text{Torquing Rate} = \frac{\text{Sin } \theta}{\text{Time}}$$

Table IV-11

TORQUING RATES - RSP

Gimbal	Phase	Run #1			Run #2			Run #3		
		Torqued		Nominal Torque Rate	Torqued		Nominal Torque Rate	Torqued		Nominal Torque Rate
		Angle	Time (sec)		Angle	Time (sec)		Angle	Time (sec)	
Roll	CW	44.15°	4.936	8.95	47.20°	5.114	9.23	45.46°	4.954	9.17
	CCW	48.51°	5.310	9.14	46.60°	5.084	9.17	48.26°	5.115	9.43
Pitch	CW	52.80°	5.215	8.75	49.90°	5.046	8.69	48.95°	4.981	8.66
	CCW	53.60°	5.195	8.88	52.95°	5.159	8.86	53.35°	5.207	8.83
Yaw	CW	59.15°	5.125	9.58	62.78°	5.337	9.54	58.90°	5.179	9.47
	CCW	58.35°	5.126	9.51	53.40°	4.788	9.60	58.65°	5.103	9.58
S. Roll	CW	49.25°	5.250	9.38	49.38°	5.130	9.62	49.60°	5.154	9.62
	CCW	49.20°	5.206	9.45	46.40°	4.999	9.30	50.00°	5.223	9.58

NOTE: All torquing rates are in deg. per sec.

NULL VOLTAGES

The synchro null voltages of the gyros used in the RSP are shown below:

Channel	Null (mv rms)
Roll	3.4
Pitch	3.0
Yaw	6.0
S. Roll	6.1

NOTE: Roll to be obtained with locking pin inserted.

SCALE FACTOR (K)

1. Outer gimbal

   a. Null gyros

   b. Check input voltage and record 26.25 vrms

   c. By rotating RSP, obtain maximum output voltage for roll and slave roll gyros. Roll to be obtained with locking pin inserted.

   d. Readings

   Roll 12.0 VAC K = .457

   S. Roll 11.8 VAC K = .449

   e. Transformation Ratio $= \frac{V\ out}{V\ in} \equiv K$

2. Inner gimbal

   a. Mount RSP on single axis table with gyro axis parallel to table axis. Follow test sequence shown below. Null gyro then turn table through angle indicated and record voltage below. Repeat for each angle. Input voltage: 26.25 VAC.

Channel	Direction	10°	20°	30°	40°	Phase
Pitch (VRMS)	CW	2.07	4.00	5.90	7.60	In
	CCW	2.13	4.02	5.98	7.76	Out
Yaw (VRMS)	CW	2.05	4.00	5.90	7.64	In
	CCW	2.05	4.00	5.90	7.60	Out

b. Transformation ratio $= \frac{V\ out}{V\ in\ \sin\theta}$

CROSS COUPLING

1. Mount RSP in single axis table and adjust gyros to give minimum cross coupling . . pitch and yaw.

2. Record below, the pitch gyro output for yaw gyro position of null, 30° CW, 30° CCW and yaw gyro output for pitch position of null, 30° CW, 30° CCW.

Channel	Null	30 CW	30 CCW
Pitch	3 mv	20 mv	20 mv
Yaw	6 mv	22 mv	22 mv

G. RATE GYROS

1. Load the output of each gyro with 10K Ω. Use 1/4 watt resistors on TB-1.

2. Mount the rate gyro assembly on the single axis table with the table rotation axis parallel to the roll rate gyro input axis. Check the output of the pitch and yaw gyros per Table IV-12. Check the output of the roll rate gyro per Tables IV-13, IV-14 and IV-15.

3. Repeat instruction 2 above for pitch gyro.

4. Repeat instruction 2 above for the yaw gyro.

Table IV-12

CROSS COUPLING - RATE GYROS

Rate Input Axis	Rate (deg/sec)	Direction	Output Axis - VRMS		
			Roll	Pitch	Yaw
Roll	30	CW		.0205	.0275
		CCW		.0155	.0240
Pitch	30	CW	.041		.025
		CCW	.0285		.035
Yaw	30	CW	.0140	.0175	
		CCW	.0095	.0142	

NOTE: All readings taken with true RMS meter, SGC 466, in Tables IV-12, IV-13, IV-14, and IV-15.

Table IV-13

ROOM TEMPERATURE SYNCHRO SCALE FACTORS - RATE GYROS

Channel	Direction	Rate (deg/sec)							
		0	2	5	7	10	20	30	40
Roll - VRMS	CW	.0105	.285	.725	1.025	1.46	2.90	4.40	5.80
	CCW	.0126	.272	.725	1.020	1.45	2.90	4.38	5.75
Pitch - VRMS	CW	.0200	.258	.690	1.000	1.41	2.82	4.25	5.65
	CCW	.0200	.274	.700	.980	1.42	2.80	4.20	5.60
Yaw - VRMS	CW	.0176	.264	.682	.950	1.37	2.72	4.10	5.40
	CCW	.0160	.263	.680	.945	1.38	2.75	4.10	5.40

Table IV-14

SYNCHRO SCALE FACTORS - RATE GYROS

Channel	Direction	Rate (deg/sec)							
		0	2	5	7	10	20	30	40
Roll - VRMS	CW	.0135	.276	.715	1.02	1.46	2.82	4.40	5.75
	CCW	.0150	.281	.725	1.02	1.46	2.92	4.40	5.75
Pitch - VRMS	CW	.0174	.261	.695	.980	1.40	2.80	4.20	5.60
	CCW	.0195	.277	.700	.985	1.42	2.82	4.25	5.60
Yaw - VRMS	CW	.0140	.260	.675	.950	1.36	2.85	4.05	5.40
	CCW	.0152	.255	.665	.950	1.36	2.70	4.10	5.40

Table IV-15

120°F SYNCHRO SCALE FACTORS - RATE GYROS

Channel	Direction	Rate (deg/sec)							
		0	2	5	7	10	20	30	40
Roll - VRMS	CW	.0155	.286	.730	1.04	1.49	2.94	4.45	5.80
	CCW	.0125	.275	.720	1.025	1.47	2.92	4.40	5.75
Pitch - VRMS	CW	.0140	.267	.690	.989	1.42	2.82	4.25	5.65
	CCW	.024	.276	.705	.990	1.43	2.85	4.20	5.60
Yaw - VRMS	CW	.0155	.270	.695	.960	1.37	2.73	4.10	5.40
	CCW	.0145	.267	.680	.945	1.36	2.72	4.10	5.40

Maximum rate gyro output voltage $[(E_o)_{max}]$ occurs at about 50 deg/sec. The maximum RMS outputs were as shown below.

Axis	Phase	$(E_o)_{max}$ Volts
Roll	CW	6.45
	CCW	6.50
Pitch	CW	6.30
	CCW	6.40
Yaw	CW	6.30
	CCW	6.30

Static inverter voltage (reading taken with Fluke meter):

ØA = 26.12 VRMS

ØB = 26.40 VRMS

H. FULL TRIGGER

1. Trigger reference voltages (room temperature/zero input):

   Positive Trigger + 0.9982 VDC

   Negative Trigger - 1.000 VDC

2. Schmitt operating characteristics (all readings are in volts DC):

Input →		@ Zero	@ Positive Trigger	@ Negative Trigger
Q_5	V_{BE}	- 1.878	0.688	- 1.880
Q_6	V_{BE}	0.716	- 1.370	0.719
Q_7	V_{BE}	- 1.069	- 1.070	0.692
Q_8	V_{BE}	0.706	0.640	- 1.426
Q_5	V_e	3.694	3.846	3.694
Q_7	V_e	3.804	3.803	3.959

	Temperature		
	Rm Temp	0^oC	70^oC
Positive Trigger - Pull In	1.106	1.107	1.104
Drop Out	1.023	1.027	1.009
Negative Trigger - Pull In	-0.870	-0.878	-0.854
Drop Out	-0.801	-0.824	-0.788
Large Signal Effects +15	None	None	None
-15	None	None	None

3. Output Voltage (Unloaded):

   Positive Trigger - ON + 6.355 VDC

   OFF - 0.545 VDC

   Negative Trigger - ON + 6.168 VDC

   OFF - 0.568 VDC

I. HALF TRIGGER

1. Trigger reference voltage: + 1.002 volts/zero input

2. Schmitt operating characteristics (all readings are in volts DC):

Input	→	@ Zero	@ Trigger
Q_3	V_{BE}	- 3.532	0.676
Q4	V_{BE}	0.702	- 1.506
Q_3	V_e	3.816	3.968

		Temperature		
		Rm Temp	$0^{o}C$	$70^{o}C$
Trigger - Pull In		1.497	1.561	1.4635
	Drop Out	1.574	1.640	1.5324
Large Signal Effects	+15	None	None	None
	-15	None	None	None

3. Output voltage: ON 0.206 VDC

   OFF 14.975 VDC

J. DEMODULATOR

Electrical and angular inputs were obtained from a position gyro synchro index head. The results of the tests performed on the demodulator are shown below.

Input Angle (Deg)	Temp (°C)	In-Phase Output (VDC)	Out-of-Phase Output (VDC)	In-Phase $\left(\frac{VDC}{Deg}\right)$	Out-of-Phase $\left(\frac{VDC}{Deg}\right)$
1/3	70	0.2017	-0.1993	.605	-.599
	25	0.2039	-0.2013	.612	-.604
	0	0.2072	-0.1989	.622	-.598
2/3	70	0.4062	-0.4025	.610	-.604
	25	0.4092	-0.4054	.615	-.609
	0	0.4124	-0.4041	.619	-.607
1	70	0.6102	-0.6080	.610	-.608
	25	0.6140	-0.6116	.614	-.612
	0	0.6179	-0.6103	.618	-.610
3	70	1.8346	-1.8370	.612	-.612
	25	1.8454	-1.8455	.615	-.615
	0	1.8523	-1.8465	.617	-.615
8	70	4.8831	-4.8983	.610	-.612
	25	4.9140	-4.9290	.614	-.617
	0	4.9266	-4.9263	.616	-.617
15	70	9.101	-9.090	.607	-.606
	25	9.156	-9.148	.611	-.610
	0	9.177	-9.147	.612	-.610
30	70	17.774	-17.624	.592	-.588
	25	17.882	-17.729	.596	-.591
	0	17.926	-17.762	.598	-.592
60	70	30.984	-30.626	.517	-.511
	25	31.210	-30.817	.520	-.514
	0	31.296	-30.881	.522	-.515
90	70	35.899	-35.486	.399	-.395
	25	36.151	-35.701	.402	-.397
	0	36.250	-35.786	.403	-.398

Ripple: In-Phase - $\frac{8}{30}$ $\frac{\text{MVP-P}}{\text{DEG}}$, Out of Phase - $\frac{8}{30}$ $\frac{\text{MVP-P}}{\text{DEG}}$

K. ABSOLUTE VALUE CIRCUIT

Electrical and angular inputs were obtained from a position gyro synchro index head. The input versus the output data results are shown below.

Input			Output (VDC)			Ripple (MVP-P)
Deg	Peak-Volts	Phase	Room Temp	0°C	70°C	Room Temp
-	0	-	0.100	0.072	0.141	
1	.290	In	0.293	0.260	0.340	8
		Out	0.293	0.258	0.338	8
3	.870	In	0.832	0.797	0.885	10
		Out	0.832	0.794	0.883	10
10	2.885	In	2.773	2.733	2.830	12
		Out	2.774	2.735	2.838	12
15	4.300	In	4.152	4.114	4.222	15
		Out	4.148	4.104	4.217	15
30	8.310	In	8.097	8.055	8.195	19
		Out	8.061	8.015	8.153	19
90	16.62	In	14.162	14.156	14.159	22
		Out	14.159	14.156	14.160	22

Transient response was measured as follows:

a. Time from maximum to minimum output resulting from removal of a large input: 2.1 seconds.

b. Time constant for large step input: .04 seconds.

Appendix V

FACS SYSTEM TEST AND CALIBRATION DATA

A. GENERAL

All system tests were performed under ambient conditions and at rated supply voltages unless otherwise specified. All AC signal inputs and angular measurements were obtained with a position gyro synchro index head.

Prior to performing the system tests, the following preliminary steps were taken:

a. The system junction box was jumpered for a "dual level detector" system configuration.

b. The RSP and rate gyro package connectors were removed from their respective subassemblies.

c. Slave roll was energized.

d. Tests were performed in ledex position 12 unless otherwise stated.

B. ROOM TEMPERATURE BENCH CALIBRATION

IACS POSITION CONTROL

Calibrated at ± 15 arc minutes for the low K_R condition with the rate control channel inputs grounded. Check at high K_R showed trigger level angular error as follows:

Channel	Direction	Trigger Input (VDC)	Input Angle (Arc Min) High K_R
Roll	CW	- 1.181	13.3
	CCW	+ 0.725	16.7
S. Roll	CW	- 1.138	--
	CCW	+ 0.819	--
Pitch	CW	- 0.942	14.0
	CCW	+ 0.667	15.8
Yaw	CW	- 0.992	14.0
	CCW	+ 0.686	15.8

IACS RATE CONTROL

This test was performed with the position channel inputs grounded. For the high K_R measurement, the appropriate gain resistor must be shorted. For calculating the resultant K_R, use the following formula:

$$\text{low } K_R = \frac{15 \text{ arc minutes}}{\text{Rate Input (arc minutes)}} \times \frac{1}{1.465}$$

$$\text{high } K_R = \frac{\text{Position Trip Point @ high } K_R{}^{*}}{\text{Rate Input (arc minutes)}} \times \frac{1}{1.465}$$

Calibration check showed:

Channel	Direction	Input Angle (Arc Min) High K_R	Input Angle (Arc Min) Low K_R	Calculation* High K_R	Calculation* Low K_R
Roll	CW	5.7	11.5	1.59	0.89
	CCW	7.5	11.6	1.52	0.88
Pitch	CW	2.7	8.1	3.54	1.26
	CCW	3.4	8.1	3.17	1.26
Yaw	CW	2.7	8.1	3.54	1.26
	CCW	3.5	8.3	3.08	1.24

The apparent difference in calculated values for CW and CCW high K_R is attributable to error associated with reading small angles. Rate gain checks were repeated by employing two synchro heads. One was used to provide simulated position inputs; the other provided simulated rate inputs. Using this method, the following data were obtained:

---

*See measured trip points in "position control" calibration.

Channel	Simulated Position Input - CW (arc min)	K_R Condition	Equivalent Angular Rate Trip Point (arc min) CW	CCW
Pitch	0	Low	7.8	8.3
	60	Low	25.1	41.0
	120	Low	58.0	73.9
	0	High	2.8	3.4
	60	High	9.9	16.0
	120	High	22.5	28.5
	180	High	34.9	41.0
Yaw	0	Low	7.7	8.5
	60	Low	25.5	41.4
	120	Low	58.6	74.7
	0	High	2.6	3.7
	60	High	10.3	16.5
	120	High	23.1	29.3
	180	High	35.8	42.0

Channel	Simulated Rate Input	K_F Condition	Equivalent Angular Position Trip Point (arc min) CW	CCW
Pitch	0	Low	14.5	15.4
	0	High	12.8	1[illegible].2
Yaw	0	Low	14.5	15.5
	0	High	12.5	17.3

Sample calculations of rate gain using "large angle" data:

Channel	K_R Condition	Calculation
Pitch	Low	$(K_R)_{CW} = \frac{120}{58.0 + 7.8} \frac{1}{1.465} = 1.24$
		$(K_R)_{CCW} = \frac{120}{73.9 - 8.3} \frac{1}{1.465} = 1.25$
Pitch	High	$(K_R)_{CW} = \frac{180 - 12.8}{34.9} \frac{1}{1.465} = 3.27$
		$(K_R)_{CCW} = \frac{180}{41.0 - 3.4} \frac{1}{1.465} = 3.27$
Yaw	Low	$(K_R)_{CW} = \frac{120}{58.6 + 7.7} \frac{1}{1.465} = 1.23$
		$(K_R)_{CCW} = \frac{120}{74.7 - 8.5} \frac{1}{1.465} = 1.23$
Yaw	High	$(K_R)_{CW} = \frac{180}{35.8 + 2.6} \frac{1}{1.465} = 3.20$
		$(K_R)_{CCW} = \frac{180 + 17.3}{42.0} \frac{1}{1.465} = 3.20$

IACS CAPTURE

Nominal Calibration -

Roll ± 90.0 arc min

Pitch ± 120.0 arc min

Yaw ± 120.0 arc min

Calibration check showed:

Channel	Direction	Input Angle (arc min)	Trigger Input (VDC)
Roll	CW	93.5	+ 1.306
	CCW	90.0	
Pitch	CW	124.3	+ 1.722
	CCW	116	
Yaw	CW	115.9	+ 1.690
	CCW	124.0	

SACS CAPTURE

Tests performed in ledex position 2. Nominal calibration. ± 18.0 arc min.

Calibration check showed:

Channel	Direction	Input Angle (arc min)	Trigger Input (VDC)
Pitch	CW	18.0	+ 0.708
	CCW	18.0	
Yaw	CW	18.3	+ 0.644
	CCW	18.3	

Note: Later changed to nominal calibration ± 24.0 arc min

SACS CONTROL

Calibrated at: ± 22.5 arc seconds x $\frac{5 \text{ mv}}{\text{arc second}}$ = ± 112 mv

Corresponding trigger voltages were as follows:

Channel	Direction	Trigger Input (VDC)
Pitch	CW	+ 0.937
	CCW	- 1.076
Yaw	CW	+ 0.952
	CCW	- 1.085

TORQUING LOOP - GYRO INPUT ONLY

The fine sensor inputs were grounded for this test.

Nominal calibration: ± 12.0 arc min

Calibration check showed:

Channel	Direction	Trigger Input (VDC)	Input Angle (arc min)
Pitch	CW	- 1.131	11.2
	CCW	+ 0.591	9.7
Yaw	CW	- 1.129	11.8
	CCW	+ 0.635	10.5

Note: Later changed nominal setting to ± 8.4 arc min

TORQUING LOOP - FINE SENSOR INPUT ONLY

The gyro inputs were grounded for this test. Simulated sensor input voltages causing trigger action were as follows:

Channel	Direction	Input (VDC)
Pitch	CW	- 0.647
	CCW	+ 0.766
Yaw	CW	- 0.707
	CCW	+ 0.830

MIXING RATIO

Test data obtained by applying simultaneous inputs simulating gyro and sensor:

Channel	Sensor Input (VDC)	Gyro Input Angle	Calc* K_M
Pitch	- 4.5 (15 $\overline{\text{min}}$)	56.8' to 1° 13' CW	4.12
Yaw	- 4.5 (15 $\overline{\text{min}}$)	55.7' to 1° 11.9' CW	4.0

*Sample Calc $K_M = \frac{71.9' - 11.8'}{15.0'} = 4.0$ (Yaw)

SYSTEM CAPTURE

The junction box was jumpered for a "single level detector" configuration for this test.

Nominal detector/trigger level: ± 24.0 arc min at gyro.

Calibration check showed:

Channel	Direction	Input Angle (arc min)
Pitch	CW	23.1
	CCW	23.1
Yaw	CW	23.1
	CCW	23.1

C. TEMPERATURE TEST

Refer to room temperature data (previous section) for test method and nominal values.

IACS POSITION CONTROL

		Input Angle (arc min)			
		Low K_R		High K_R	
Channel	Direction	40°F	120°F	40°F	120°F
Roll	CW	15.2	15.1	13.6	13.2
	CCW	15.3	14.9	16.8	16.8
S. Roll	CW	15.7	15.2		
	CCW	14.7	14.7		
Pitch	CW	15.6	15.2	14.3	14.2
	CCW	15.0	14.6	16.2	15.6
Yaw	CW	15.1	15.2	14.1	14.0
	CCW	14.9	14.6	16.0	15.8

IACS RATE CONTROL

		Input Angle (arc min)			
		Low K_R		High K_R	
Channel	Direction	40°F	120°F	40°F	120°F
Roll	CW	5.8	5.6	11.5	11.6
	CCW	7.3	7.5	11.7	11.6
Pitch	CW	2.8	2.8	8.2	8.2
	CCW	3.3	3.2	7.9	7.9
Yaw	CW	2.8	2.8	8.0	8.2
	CCW	3.4	3.5	8.1	8.1

IACS CAPTURE

Channel	Direction	Input Angle (arc min) 40°F	120°F
Roll	CW	101.4	92.5
	CCW	97.5	88.0
Pitch	CW	131.1	122.8
	CCW	123.5	114.7
Yaw	CW	131.9	122.7
	CCW	124.5	115.0

SACS CAPTURE

Channel	Direction	Input Angle (arc min) 40°F	120°F
Pitch	CW	20.4	16.9
	CCW	21.7	16.8
Yaw	CW	20.5	17.4
	CCW	20.7	17.6

SACS CONTROL

Channel	Direction	Input (VDC) 40°F	120°F
Pitch	CW	- .109	- .111
	CCW	+ .113	+ .113
Yaw	CW	- .114	- .109
	CCW	+ .109	+ .111

TORQUING LOOP - GYRO INPUT

Channel	Direction	Input Angle (arc min) 40°F	120°F
Pitch	CW	11.2	11.0
	CCW	10.5	9.9
Yaw	CW	12.1	11.8
	CCW	10.2	10.5

TORQUING LOOP - FINE SENSOR INPUT ONLY

Channel	Direction	Input (VDC) 40°F	120°F
Pitch	CW	- .638	- .649
	CCW	+ .776	+ .781
Yaw	CW	- .687	- .712
	CCW	+ .838	+ .834

SYSTEM CAPTURE

Channel	Direction	Input Angle (arc min) 40°F	120°F
Pitch	CW	24.9	22.8
	CCW	24.8	23.9
Yaw	CW	25.3	23.3
	CCW	24.6	23.7

Appendix VI

BREADBOARD FACS
TELEMETRY SIGNAL-CONDITIONER CALIBRATION

NOTE: Directional notation (CW or CCW) represents sign of jet turn-on resulting from indicated signal.

Function	J18	Condition	Output - VDC 24V	28V	34V
Roll Valves	1	None	3.699	4.256	5.170
		Despin	2.793	3.253	3.946
		CW	2.614	3.045	3.693
		CCW	1.979	2.300	2.785
		Not Armed	0	0	0
Pitch H.T. Valves	2	None	3.563	4.153	5.045
		CW	1.510	1.740	2.092
		CCW	2.240	2.599	3.143
		After Switchover	0	0	0
Yaw H.T. Valves	3	None	3.552	4.142	5.030
		CW	1.505	1.735	2.085
		CCW	2.231	2.589	3.130
		After Switchover	0	0	0
Pitch L.T. Valves	6	None	3.496	4.080	4.936
		CW	1.400	1.626	1.963
		CCW	2.173	2.531	3.060
		Before Switchover	0	0	0

Function	J18	Condition	Output - VDC		
			24V	28V	34V
Yaw L.T. Valves	7	None	3.559	4.152	5.025
		CW	1.421	1.650	1.985
		CCW	2.219	2.585	3.122
		Before Switchover	0	0	0
Pitch Valve Switchover	29	Before	0	0	0
		After	3.770	4.386	5.329
Yaw Valve Switchover	27	Before	0	0	0
		After	3.905	4.544	5.519
Roll Capture	39	Before	0	0	0
		After	3.374	3.909	4.705
Pitch Capture	40	Before	0	0	0
		After	3.764	4.401	5.349
Yaw Capture	41	Before	0	0	0
		After	3.830	4.480	5.444
Torque Loop Closure	28	Before	3.766	4.396	5.330
		After	0	0	0
Program Position	4	12	0	0	0
		1	4.88	4.90	4.91
		2		4.43	
		3		3.98	
		4		3.53	
		5		3.08	
		6		2.63	
		7		2.19	
		8		1.75	
		9		1.31	
		10		0.88	
		11		0.44	

Function	J18	Condition	Output - VDC		
26 V /0°	10			2.20	
26 V /+90°	11			2.42	
+15 VDC Monitor	8			2.663	
-15 VDC Monitor	9			2.432	
+5 VDC TLM REF	14			4.90	
400-CPS Freq Monitor	12		8.1 VRMS MAX (Set for 5.0 VRMS)		
Roll Torquer	18	ON		4.55	
		OFF		0	
Pitch Torquer	17	ON		4.53	
		OFF		0	
Yaw Torquer	16	ON		4.50	
		OFF		0	
S. Roll Torquer	15	ON		4.57	
		OFF		0	
SACS State	26	IN		3.71	
		OUT		0	
			24V	28V	34V
"G" Switch & Arm Roll	5	Neither	0	0	0
		"G" Switch Only	1.425	1.667	2.029
		Arm Roll Only	2.413	2.817	3.419
		Both	3.687	4.303	5.223

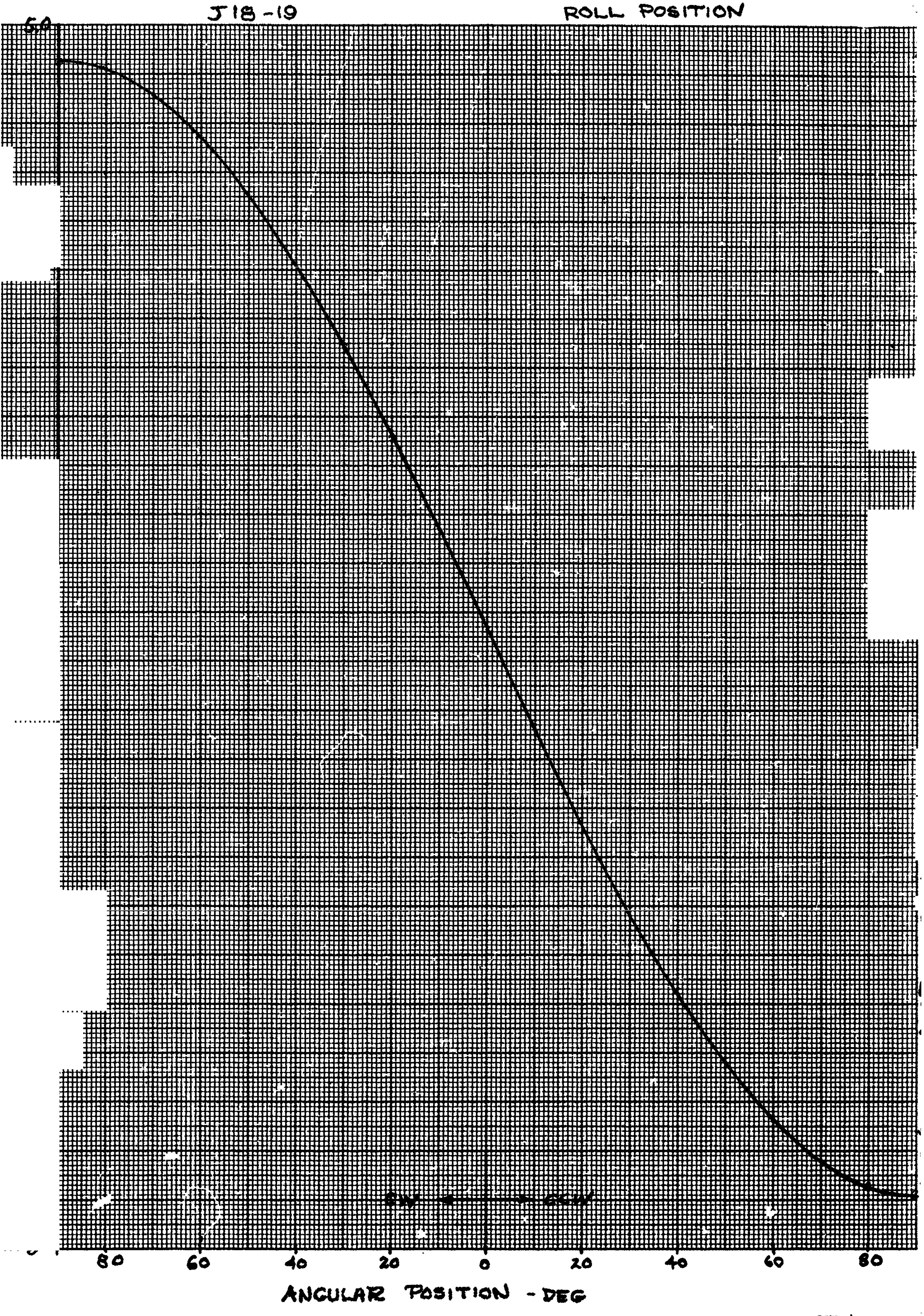


Figure VI-1. Telemetry Calibration Roll Position

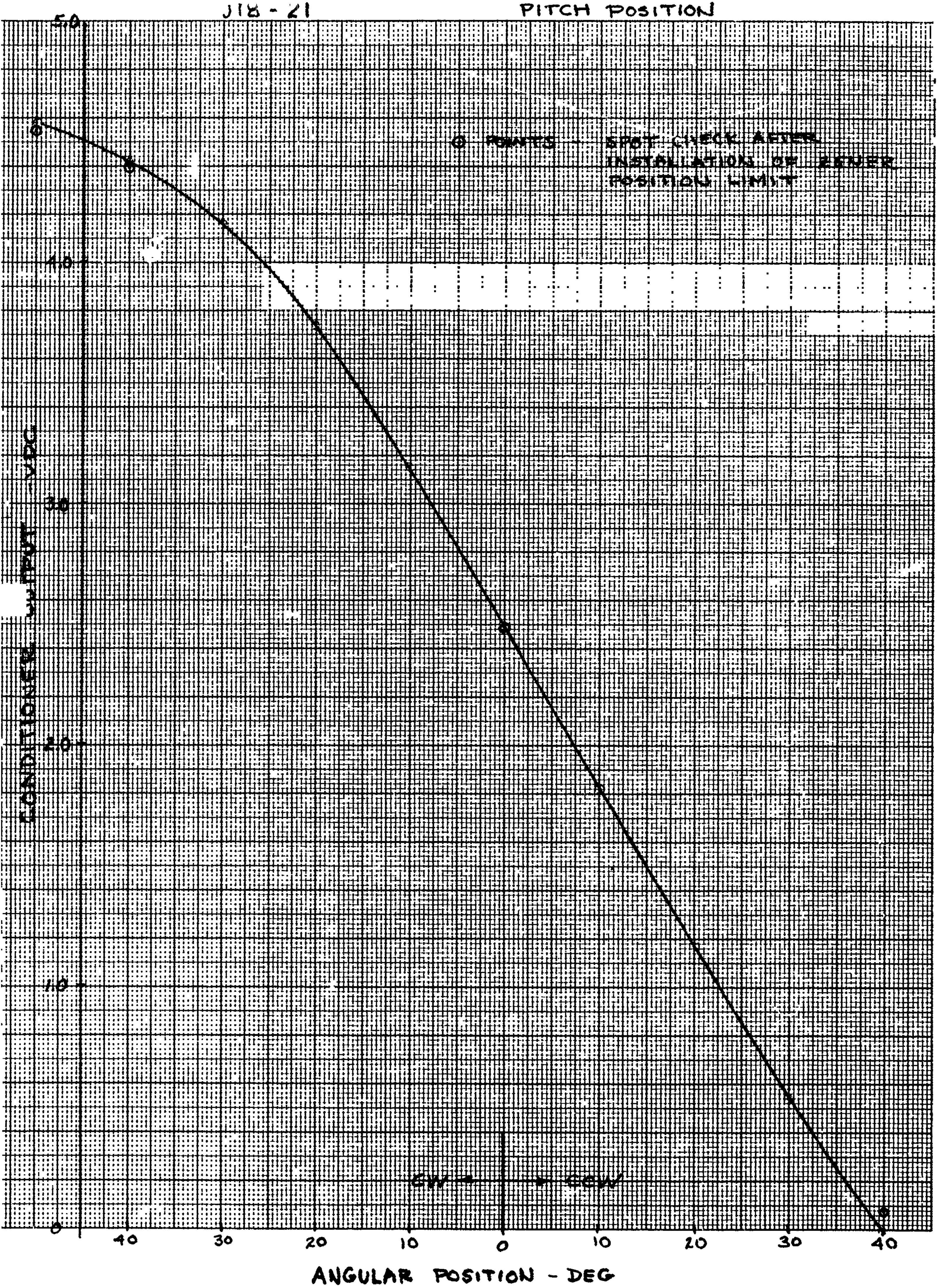


Figure VI-2. Telemetry Calibration Pitch Position

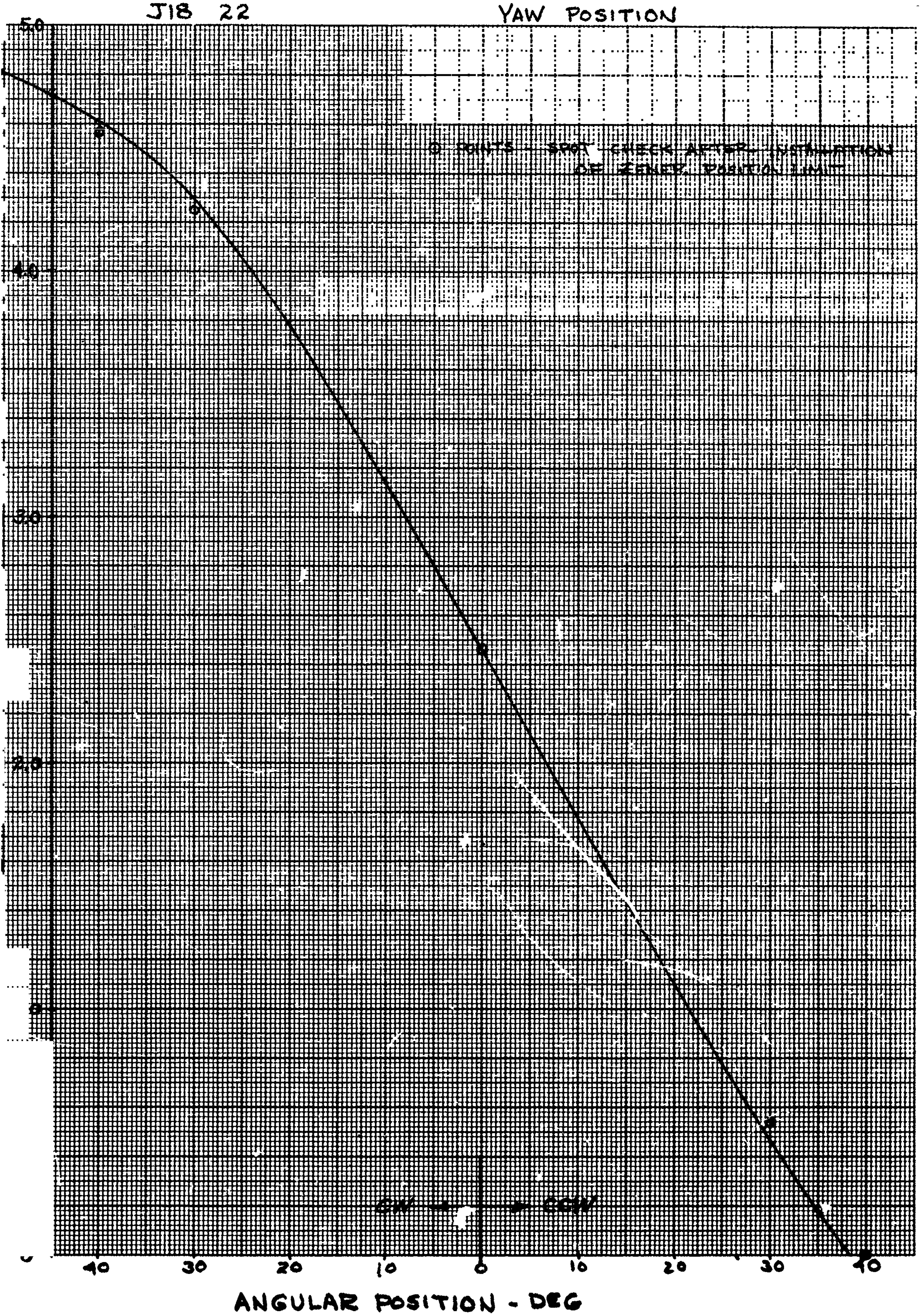


Figure VI-3. Telemetry Calibration Yaw Position

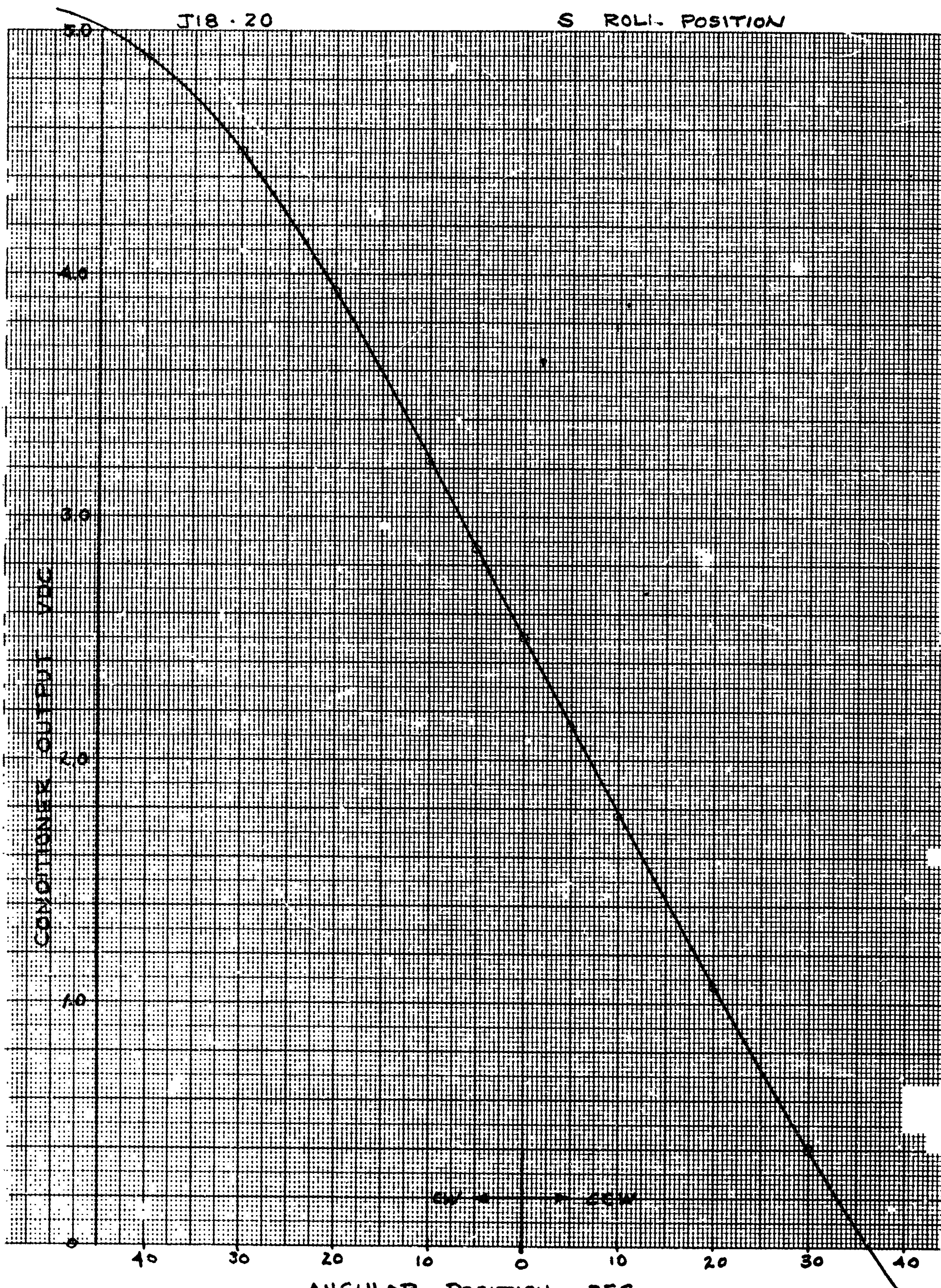


Figure VI-4. Telemetry Calibration Slave Roll Position

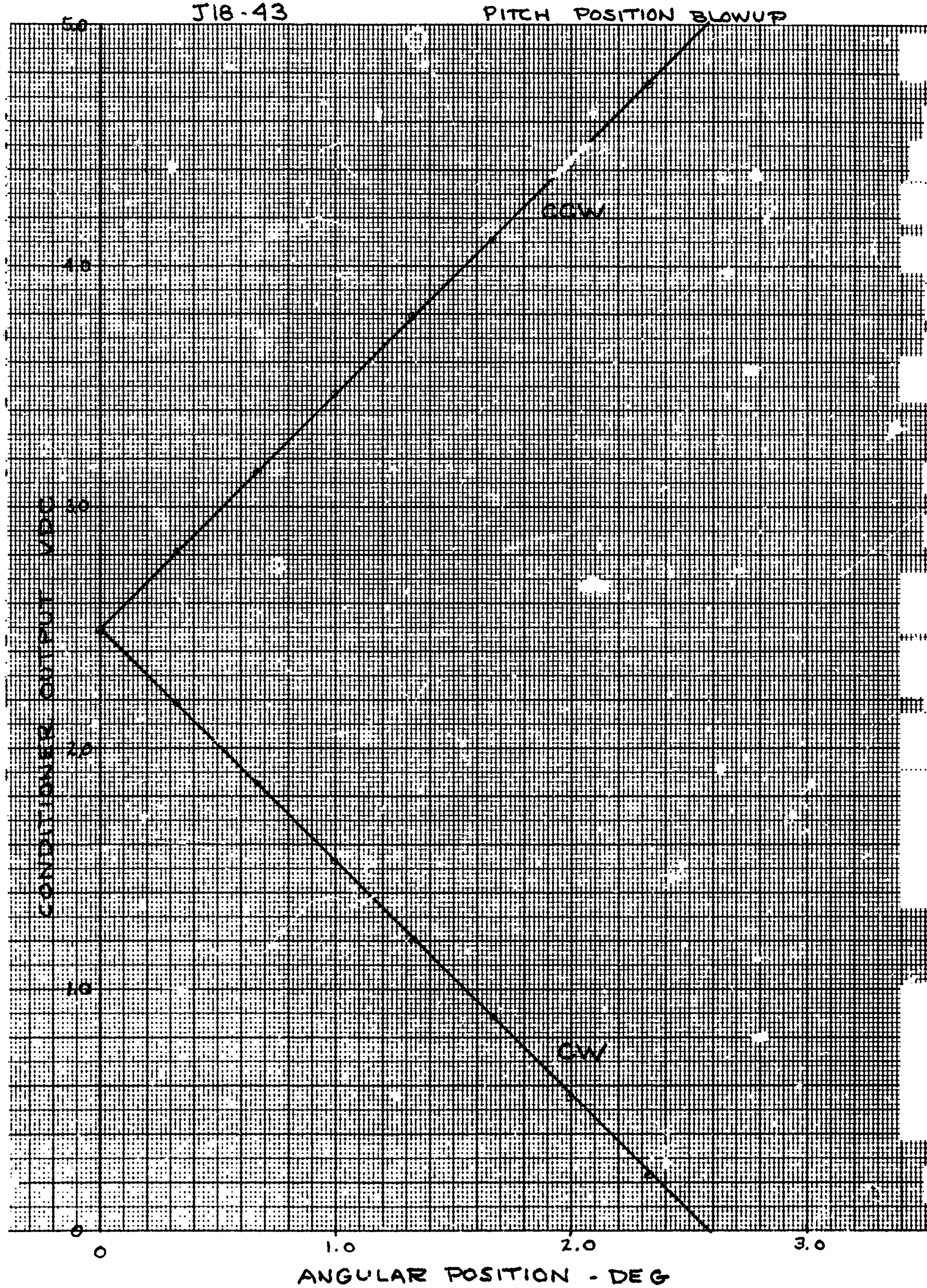


Figure VI-5. Telemetry Calibration Pitch Position Blowup

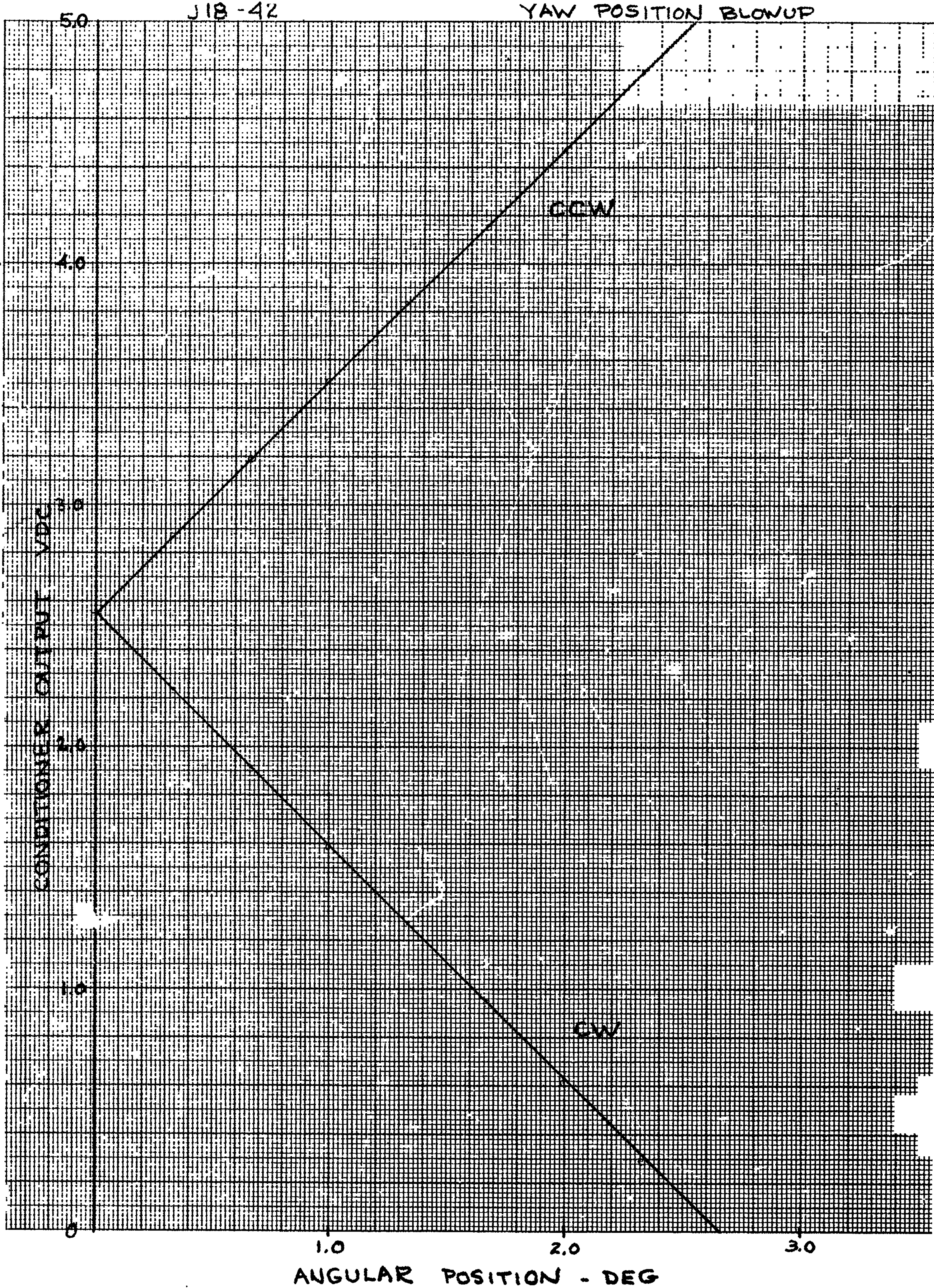


Figure VI-6. Telemetry Calibration Yaw Position Blowup

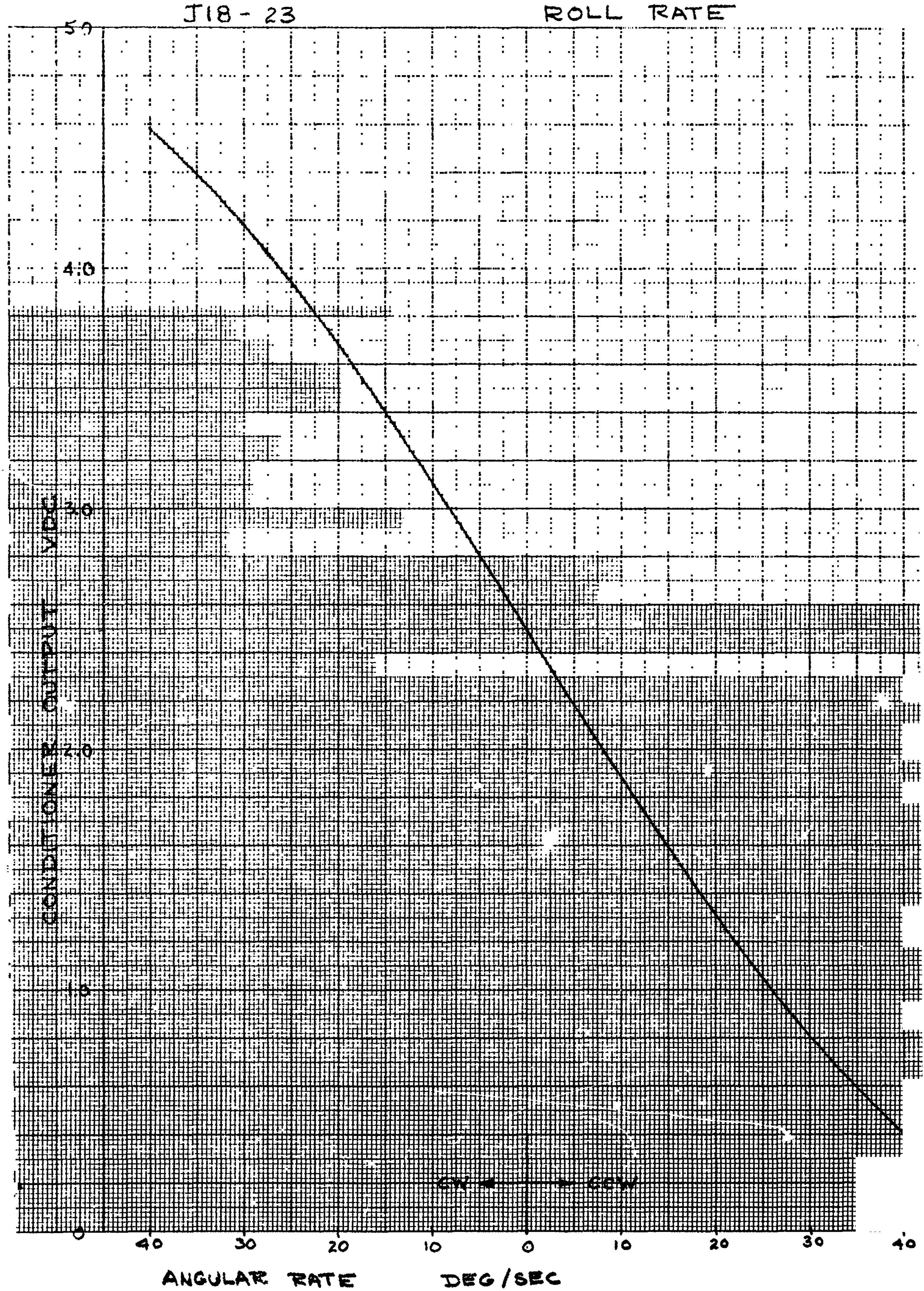


Figure VI-7. Telemetry Calibration Roll Rate

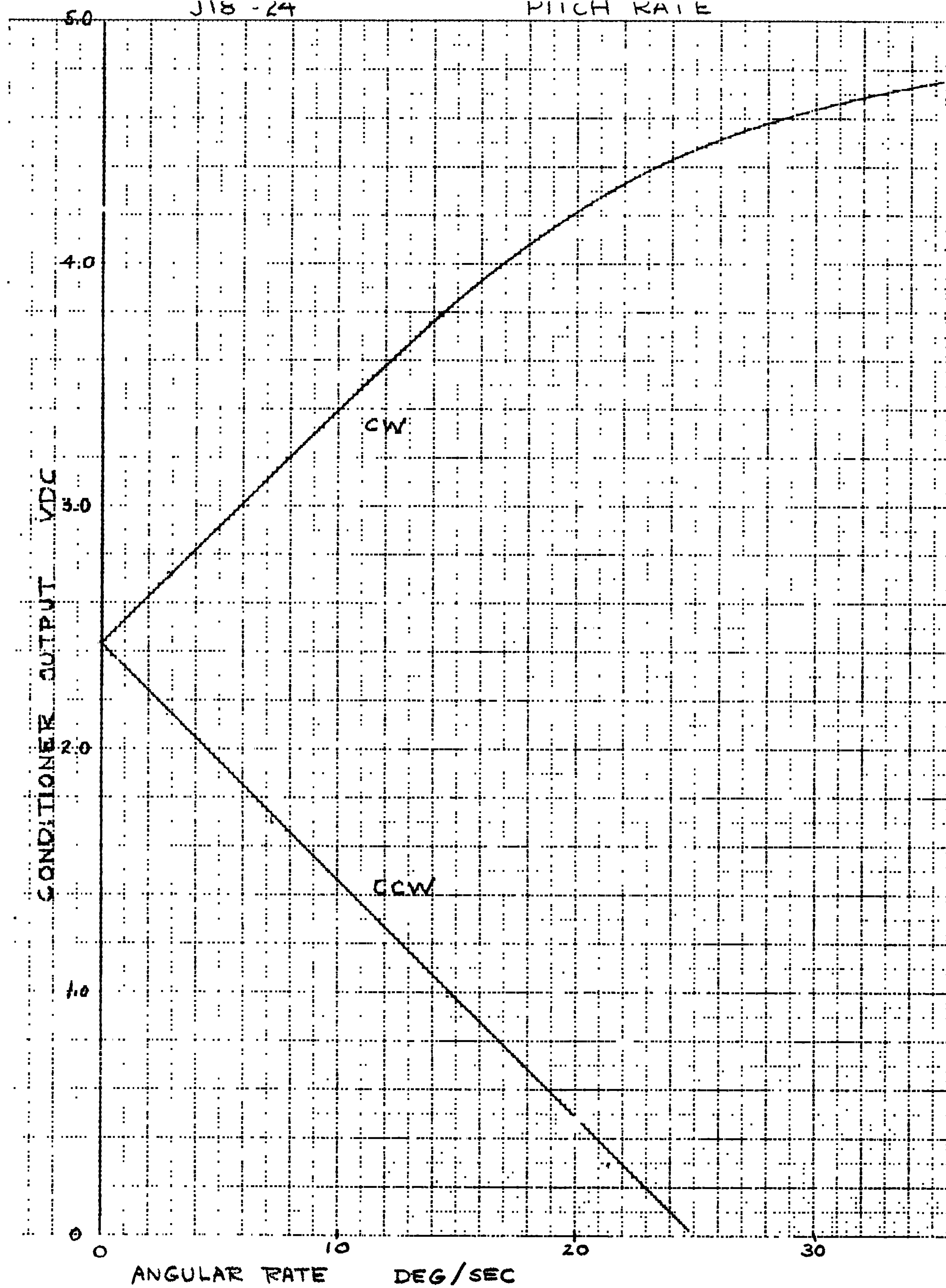


Figure VI-8. Telemetry Calibration Pitch Rate

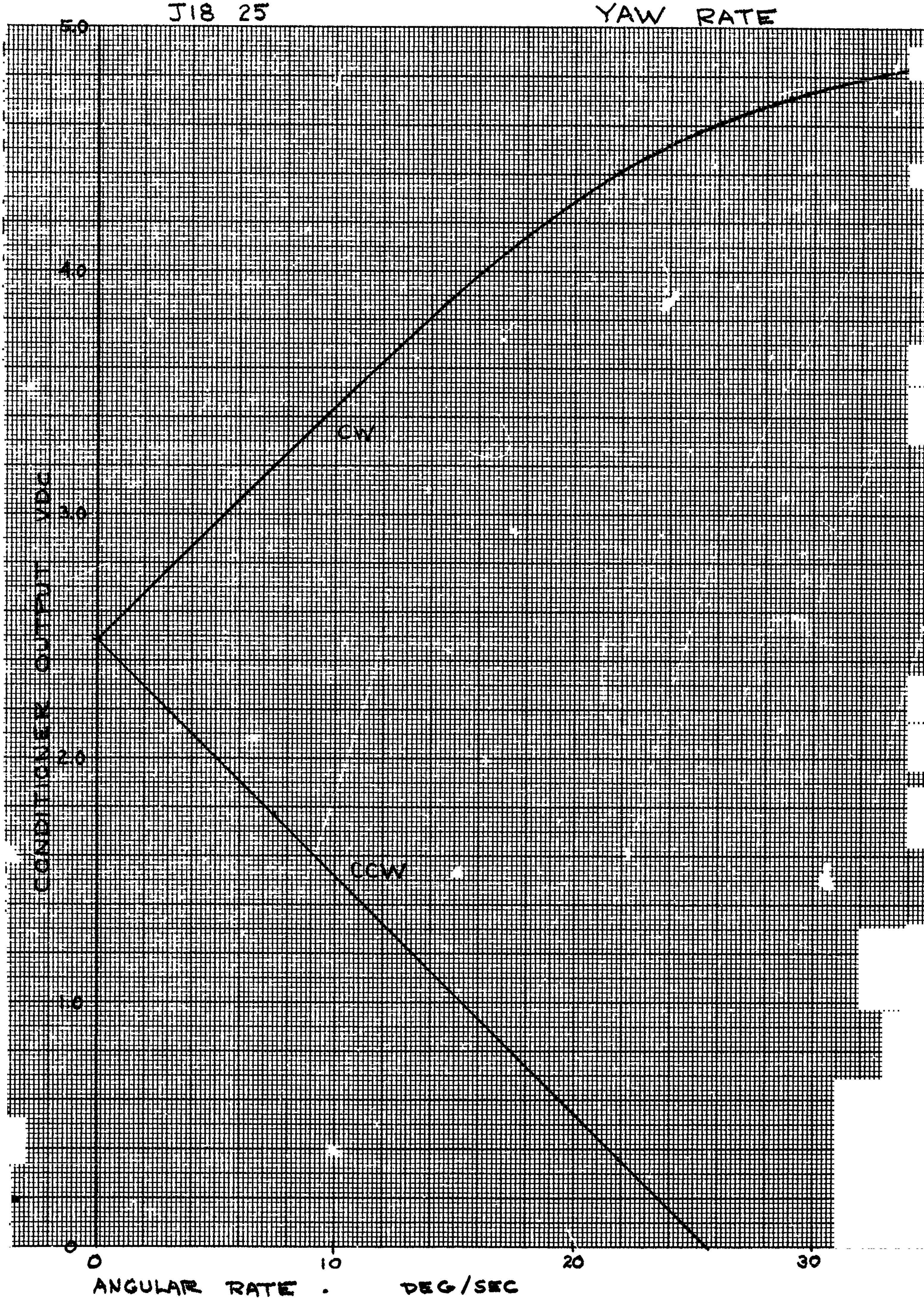


Figure VI-9. Telemetry Calibration Yaw Rate

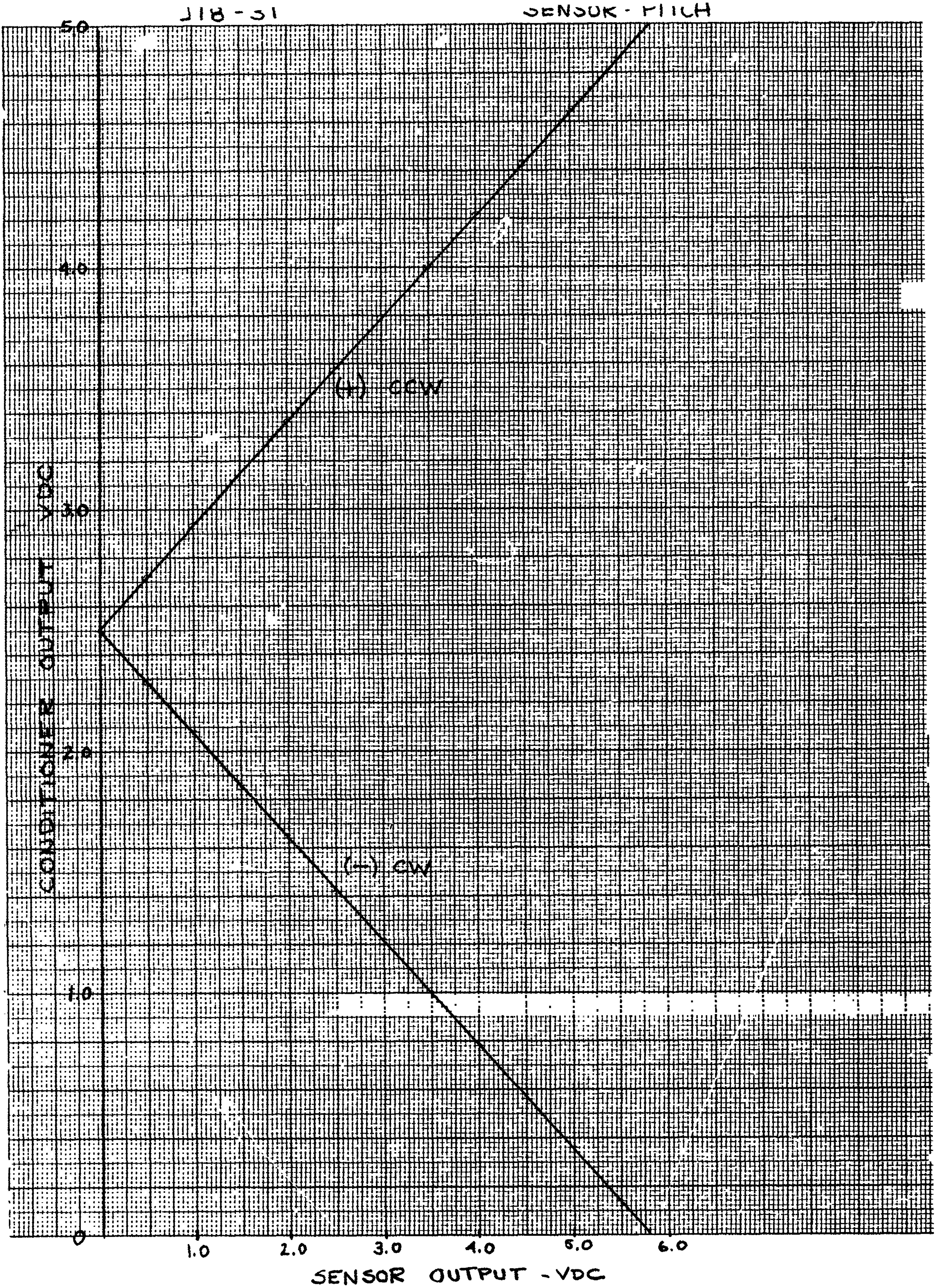


Figure VI-10. Telemetry Calibration, Sensor-Pitch

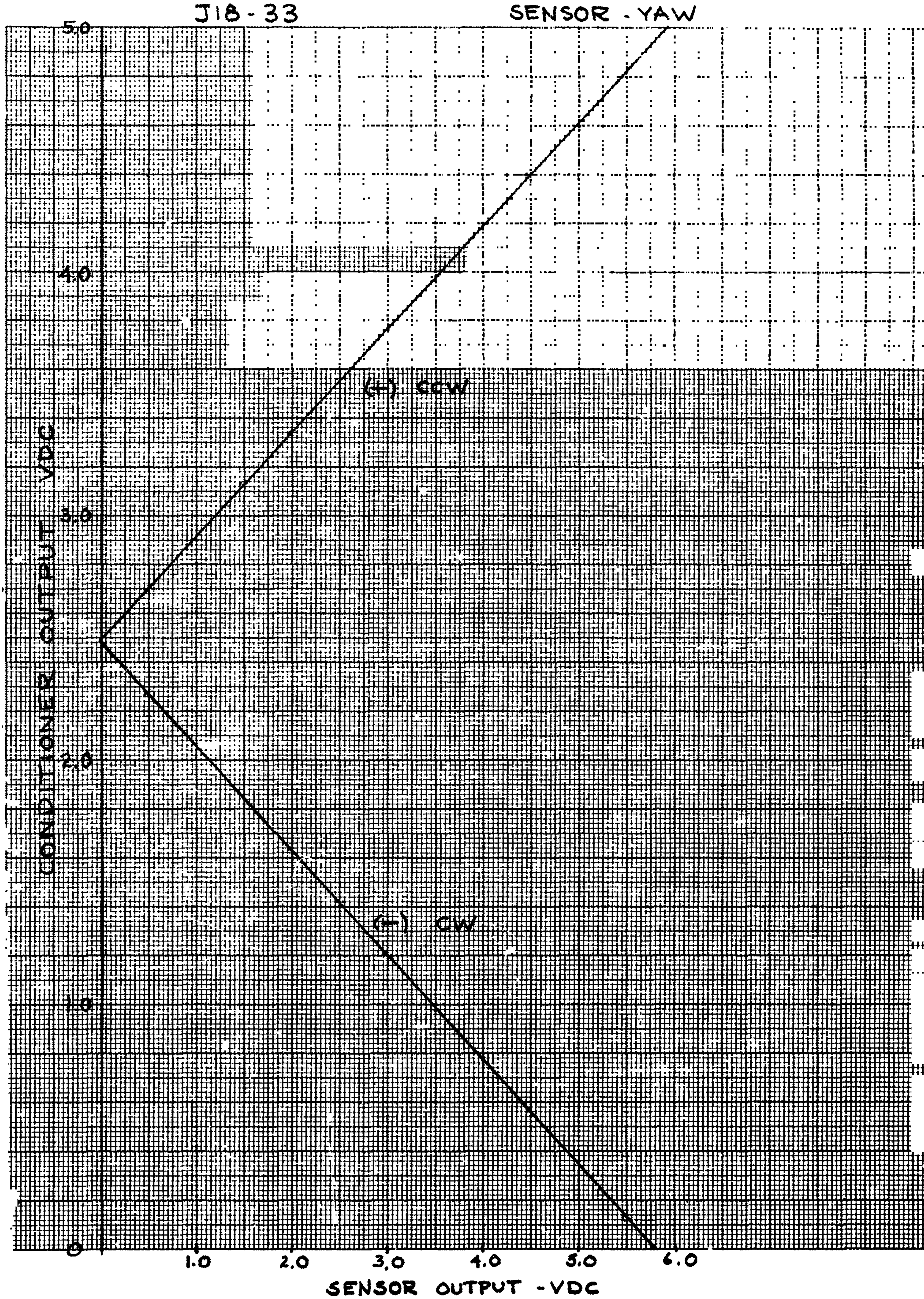


Figure VI-11. Telemetry Calibration, Sensor-Yaw

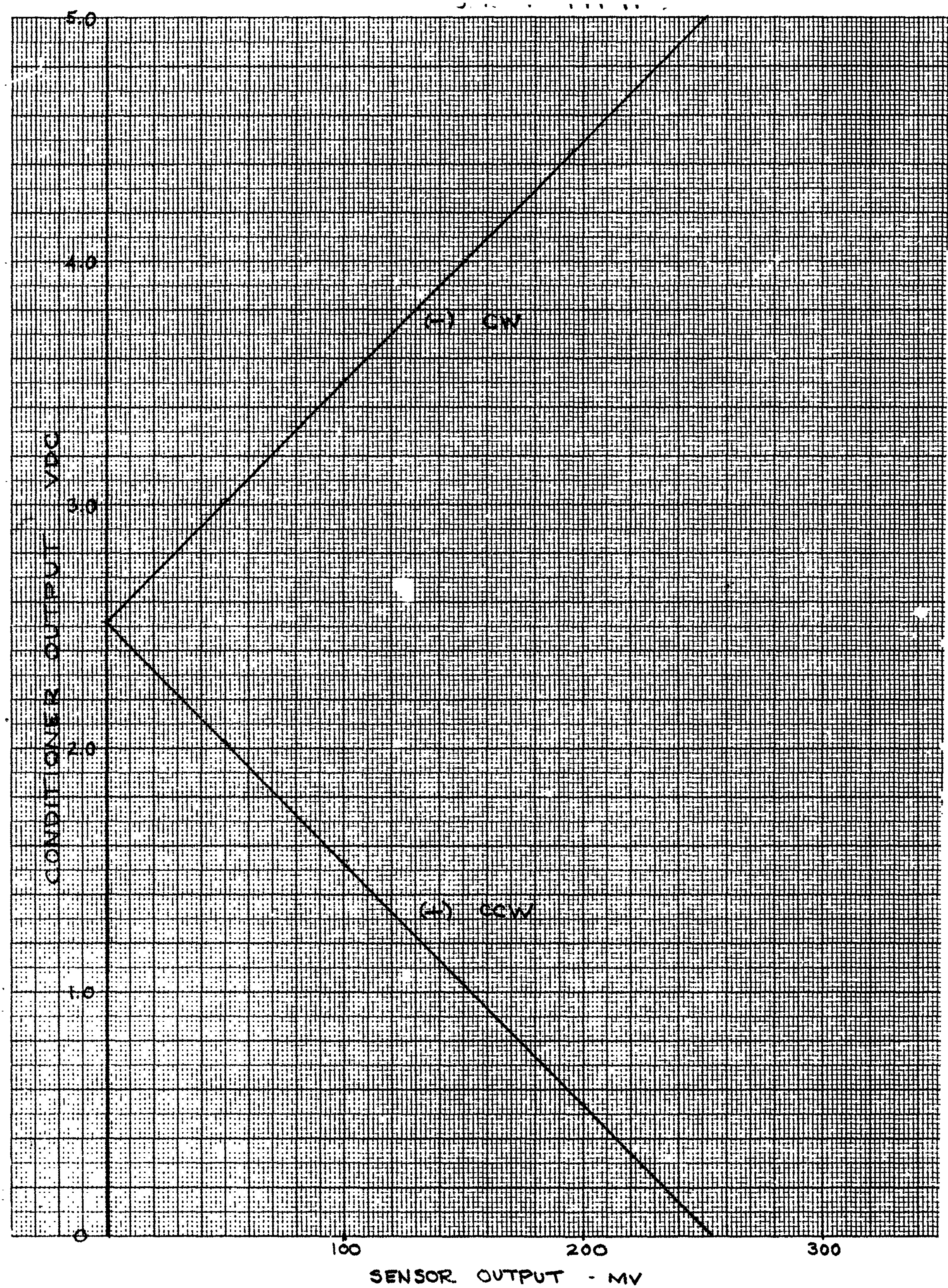


Figure VI-12. Telemetry Calibration, Sensor-Pitch X10

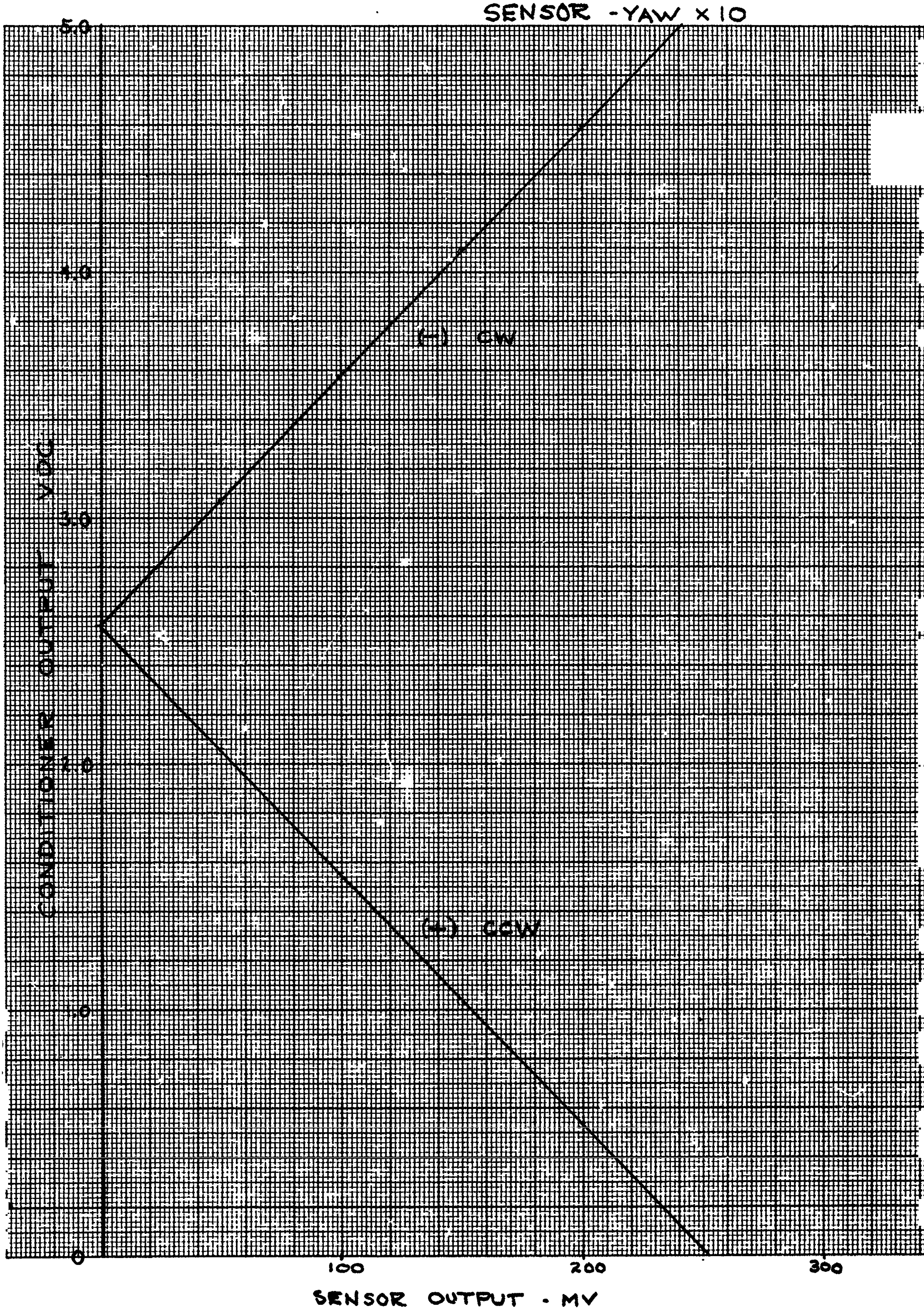


Figure VI-13. Telemetry Calibration, Sensor-Yaw X10

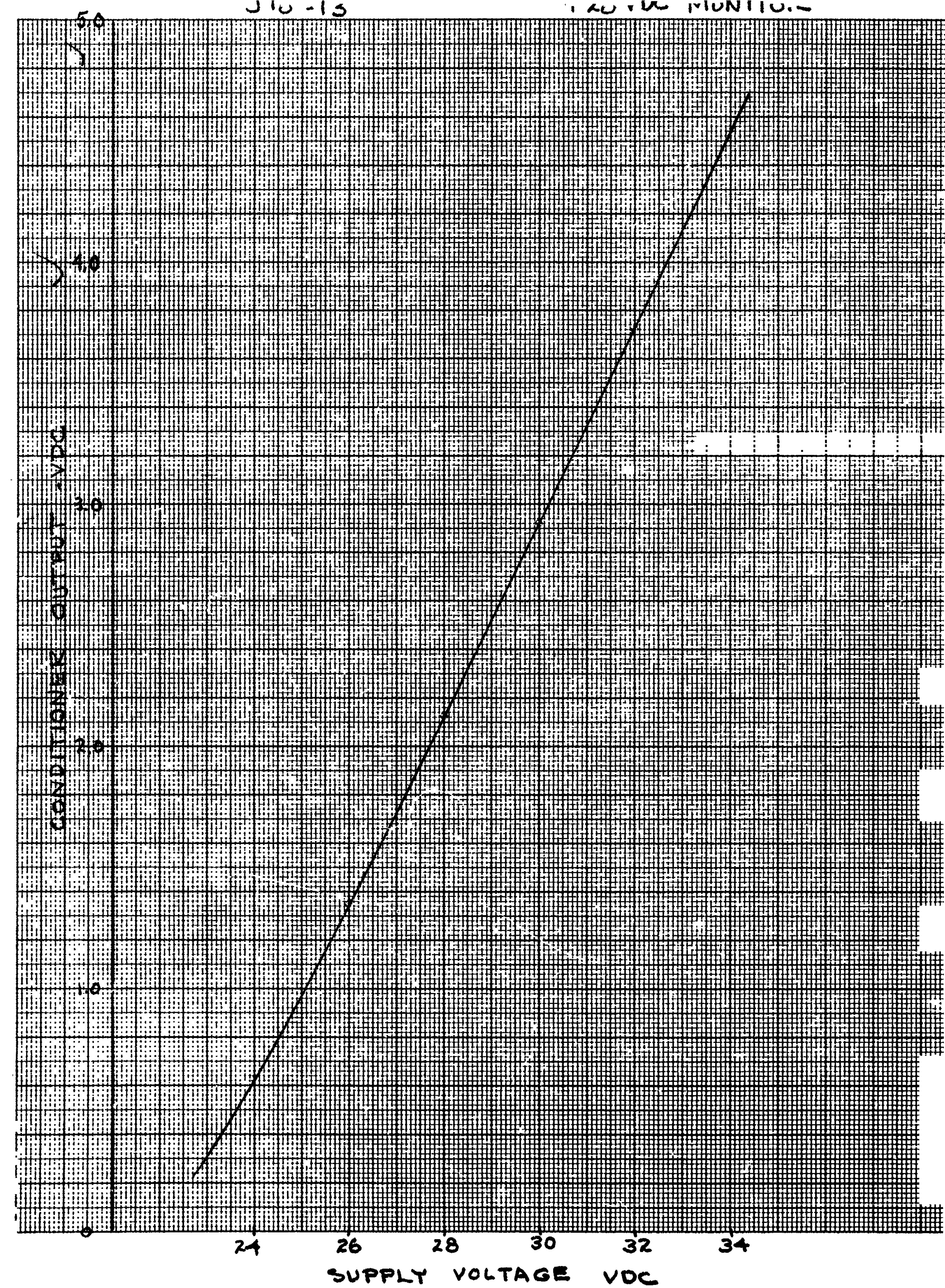


Figure VI-14. Telemetry Calibration, +28 VDC Monitor

Appendix VII

OPERATIONAL PROCEDURES AND PARAMETER CHANGES

A. AIR BEARING SIMULATOR TESTS

FACS MODE

When the full FACS is operated with a complete program, the following operational steps are used.

1. Initial Console Settings:

    a. Console AC power switch "OFF"

    b. Console main power supply "OFF"

    c. +28 VDC switch "OFF"

    d. +15 VDC switch "OFF"

    e. -15 VDC switch "OFF"

    f. Vehicle Power control switch "OFF"

    g. Program Stop switch in down position

    h. Offset caging switches (3) in "NULL" position

    i. Offset caging synchros aligned to zero degrees

    j. Offset caging configuration switch for each axis should be in the mode desired, either 2 wire or 3 wire. The three switches are located inside the console. The 3-wire configuration should be used only when using gyros that have their synchro third wire brought out.

2. Connect umbilical from GSE to FACS.

3. Turn "ON" console AC Power switch.

4. Turn "ON" console main power supply (adjust for 30 V).

5. Turn "ON" +28 VDC switch.

6. Turn "ON" +15 VDC switch.

7. Turn "ON" -15 VDC switch.

8. Turn Vehicle Power control switch to "EXT."

   NOTE: The Program Position indicator should be on position 12. If the indicator reads anything but 12, the Vehicle Power control switch should be immediately returned to the "OFF" position. To correct the condition, remove the connector to the RSP, place the Program Stop switch in the up position, turn the Vehicle Power control switch to "EXT" and pulse the Program Advance button on the console until the Program Position indicator reads 12. Turn the Vehicle Power control switch to "OFF", return the Program Stop switch to the down position, reconnect the RSP connector, and proceed with the test.

9. Allow approximately one minute for the Vehicle DC Current to drop to the steady state running current: approximately 6 amps with telemetry and 5 amps without telemetry.

10. Depress Cage button until the Roll, Pitch, Yaw, and S. Roll Null lights come "ON", then release Cage button.

11. Align vehicle to initial orientation for test and depress Cage button until all four Null lights come "ON" again. Release Cage button.

12. Turn Vehicle Power control switch to "INT".

13. Depress Cage button until all four Null lights again come "ON" and stay on. Release cage button.

14. Remove umbilical from FACS.

15. Start Vehicle Timer.

16. <u>Test with Despin</u> - Spin vehicle CCW looking aft from the nose of simulator.

17. <u>Test without Despin</u> - Turn vehicle slightly CW looking aft from the nose of the simulator - about 15 degrees.

18. At the completion of the program, insert the umbilical into the FACS, turn the Vehicle Power control switch to "EXT", place the Program Stop switch in the up position, pulse the Program Advance until the Program Position indicator reads 12 and then turn the Vehicle Power control switch to "OFF".

<u>EMERGENCY PROCEDURE</u>: If at any time the FACS indicates that a failure has occurred while on the Air Bearing Simulator, the emergency procedure is to turn "OFF" the vehicle battery power supplied to the FACS and insert the umbilical into the FACS. <u>If the gyros have not spun down</u> the following procedure can be used to re-establish the program sequence.

1. Place Program Stop in up position.

2. Turn the Vehicle Power control switch to "EXT".

3. Cage.

4. Pulse Program Advance until the Program Position indicator reads 12 and then turn the Vehicle Power control switch to "OFF".

If the gyros have spun down, the note of step 8 above is applicable.

IACS MODE

When the FACS is operated with a complete program, the operational steps of the FACS Mode above are applicable.

SACS ONLY MODE

When the FACS is operated in the SACS ONLY Mode, the operational steps are as follows:

1. The Program Stop function must be jumpered to ground in the "J" box.

2. Steps 1 through 10 of the FACS Mode above are applicable.

3. Turn Vehicle Power control siwtch to "INT".

4. Cage gyros, with the vehicle somewhere close to the light source, and pulse the Program Start button.

5. Continue to cage gyros and pulse the Program Advance until the Program Position indicator reads 2. When the FACS coast time delay times out, the system will switch over into SACS operation and the vehicle may then be placed within the field of the light source. Release the Cage button and pull the umbilical before the acquisition is attempted.

6. When the test is complete, put the umbilical back into FACS, turn the Vehicle Power control switch to "EXT", pulse the Program Advance button until the Program Position indicator reads 12 and then turn the Vehicle Power control switch to "OFF".

OFFSET CAGING

1. Two-Wire Configuration - Place the caging configuration switch in the back of the console to the 2 position for the channels desired. Offset caging is accomplished by turning the offset caging selector switch to the direction desired and setting the magnitude of the offset with the potentiometer directly below each selector switch in each channel. For accurate offsetting, a Ratiometer must be used to take the ratio of the gyro synchro output voltage and the 26 V zero degree reference phase of the FACS. Using the equation below, the ratio desired can be calculated.

$$\frac{E_{out}}{E_{in}} = T_R \sin \theta = .453 \sin \theta$$

An alternate, less accurate, method is to read out the synchro voltage on a true rms voltmeter and calculate the angle using

$$E_{out} = 11.75 \sin \theta$$

2. Three-Wire Configuration - Place the caging configuration switches in the back of the console to the 3 position for the channels desired. Change the gain of the caging channels being used in the 3-wire configuration by a factor of two by jumpering the two feedback resistors on the console circuit boards. To offset cage, set each channel synchro on the console to the angle desired and cage the gyros. The four console Null lights will indicate when the offset is complete.

B. SYSTEM PARAMETER CHANGES

Parameter		Component		Unit
		Value	Designation	
Mixing Ratio	2	2.7 M	R17 and R22	SACS
	3	1.8 M	R17 and R22	SACS
	4	1.3 M	R17 and R22	SACS
Single Detector Level	.3 deg	2.0 M	R5 and R6	IACS
	.4 deg	1.5 M	R5 and R6	IACS
Dual Detector Level	.3 deg	1.8 M	R3 and R4	SACS
	.4 deg	1.3 M	R3 and R4	SACS
K_r - Pitch & Yaw	1.58	Jumper	R44 and R45	IACS
	1.58 1.25	No Jumper	R44 and R45	IACS

C. FINE CONTROL STATIC SWITCHING LEVELS - SACS

A change in the SACS control deadband is achieved by simulating the fine sensor with the circuit in Figure VII-1 and adjusting the trigger levels of the control channels in accordance with Table VII-1.

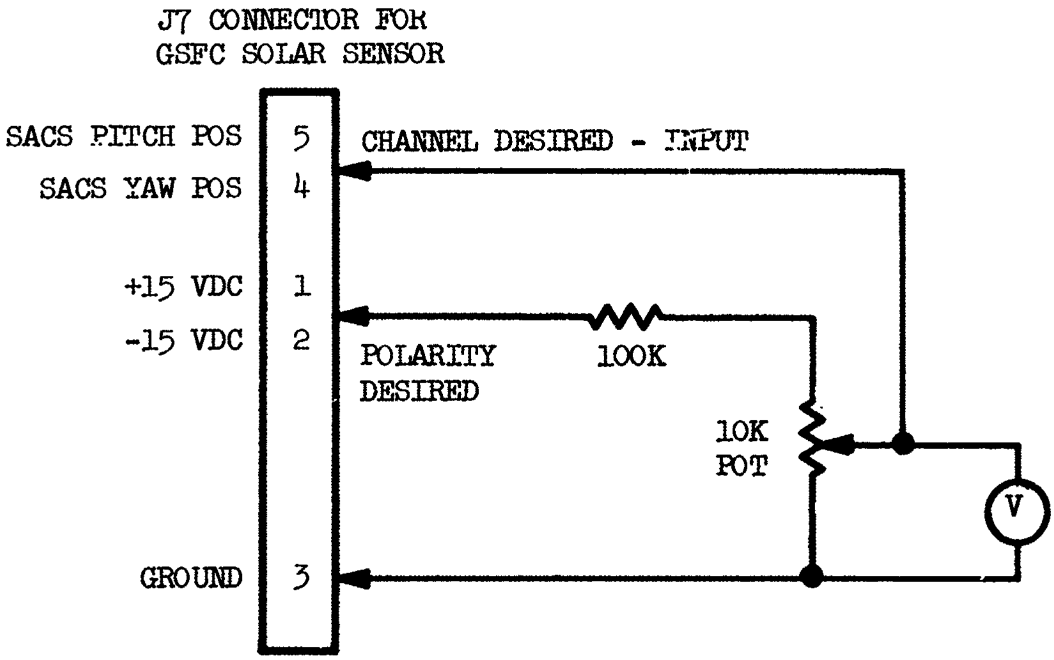


Figure VII-1. Fine Sensor Simulator Circuit

Table VII-1

SACS Control Deadband	Input (mvdc)	Channel	Adjust Pot	Circuit Values
± 22.5 $\overset{\frown}{\text{sec}}$	+ 112	Pitch	ZR4	R27 = 2M
	-112	Pitch	ZR3	R30 = 2M
	+112	Yaw	ZR10	C7 = .015 µf
	-112	Yaw	ZR9	C12 = .015 µf
± 10 $\overset{\frown}{\text{sec}}$	+50	Pitch	ZR4	R27 = 2M
	-50	Pitch	ZR3	R30 = 2M
	+50	Yaw	ZR10	C7 = .015 µf
	-50	Yaw	ZR9	C12 = .015 µf
± 7.4 $\overset{\frown}{\text{sec}}$	+37	Pitch	ZR4	R27 = 2M
	-37	Pitch	ZR3	R30 = 2M
	+37	Yaw	ZR10	C7 = .015 µf
	-37	Yaw	ZR9	C12 = .015 µf
± 4.9 $\overset{\frown}{\text{sec}}$	+25	Pitch	ZR4	R27 = 3M
	-25	Pitch	ZR3	R30 = 3M
	+25	Yaw	ZR10	C7 = .01 µf
	-25	Yaw	ZR9	C12 = .01 µf

D. SYSTEM CONFIGURATION CHANGES

All major system configuration changes are made in the FACS junction box at the system configuration patchboard. Figure VII-2 shows the jumpers required for the system configuration desired.

E. HOLD TIME DELAYS

The duration of the hold time delays are determined by resistors R30, R31, R32, and R33 in the programmer subassembly. Each of these resistors determines a separate hold time delay. Resistance values for these resistors versus the desired hold time delays are shown in Figure VII-3.

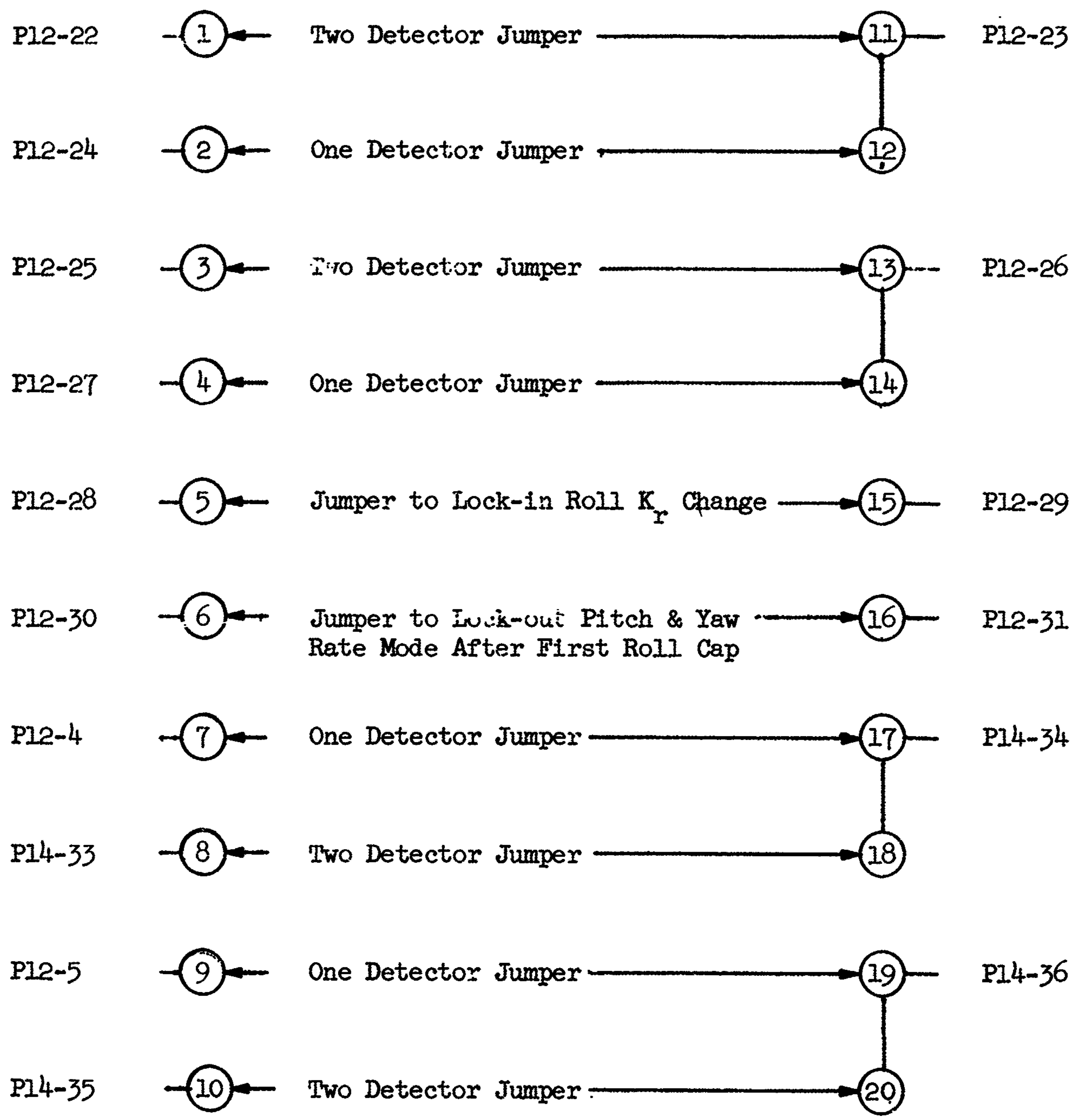


Figure VII-2. System Configuration Patchboard

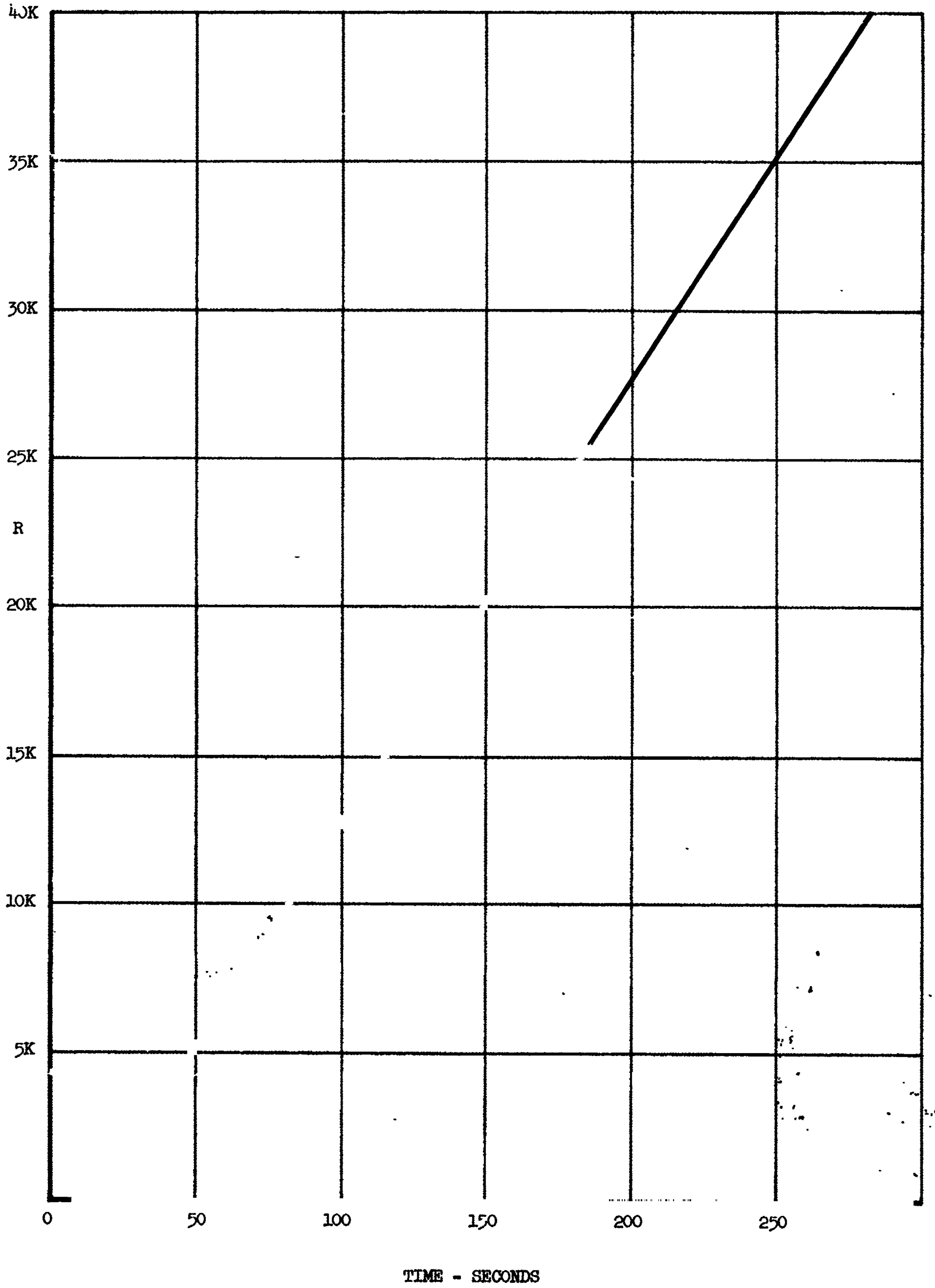


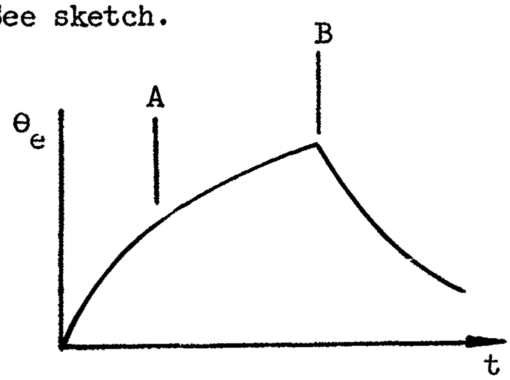
Figure VII-3. Hold Time Delay Resistance

Appendix VIII

FACS TECHNICAL NOTE
RE-EVALUATION OF RAMP MANEUVER CHARACTERISTICS

A. INTRODUCTION

The first FACS air bearing test (March 3, 1965) showed 75° ramp maneuver with no steady-state condition (i.e. lag angle, θe, never became constant). See sketch.



A to B - Showed two-sided jet action--indicating operation on switching line

at B - Gyro torquing stopped

Note: $\theta e \neq$ constant

B. DISCUSSION

The analysis (summarized below) shows this performance to be expected but, heretofore not recognized because the effect of large gimbal angles on gyro torquing rate was neglected.

That is, past analysis, analog, etc., had used:

Gyro torquing rate, $\dot{\theta}g = R$

where R = zero-lag-angle torquing rate (normally approximately 9 deg/sec).

The correct expression is:

$$\dot{\theta}g = \frac{R}{\cos \theta e} \qquad \text{(VIII-1)}$$

where lag angle $\theta e = \theta g - \theta v$

θg = Gyro Attitude

θv = Vehicle Attitude

C. EXPRESSION FOR STEADY-STATE LAG ANGLE

Switching equation (large angle):

$$57.3 \sin \theta e - K_R \dot{\theta} v = 0 \qquad \text{(VIII-2)}$$

Steady-state condition requires:

$$\dot{\theta} v = \dot{\theta} g \qquad \text{(VIII-3)}$$

(i.e. θe = const)

From above:

Steady-State Lag Angle:

$$\theta e = 1/2 \sin^{-1} \left(\frac{2R}{57.3} K_R \right) \qquad \text{(VIII-4)}$$

We observe that Equation (VIII-4) implies an upper limit on K_R for the steady-state condition to exist. Upper limit given by:

Maximum Rate Gain

$$(K_R) \max = \frac{57.3}{2R} \qquad \text{(VIII-5)}$$

Ex: if R = 9.0 deg/sec, (K_R) max = 3.18

The significance of this is discussed below.

D. PHASE-PLANE REPRESENTATION

A phase-plane plot of gyro torquing rate, $\dot{\theta} g$, and vehicle rate, $\dot{\theta} v$, versus lag angle, θe, is shown in Figure VIII-1, plotted from Equations (VIII-1) and (VIII-2).

Note that, for a steady-state condition to exist, there must be an intercept between the $\dot{\theta} g$ and $\dot{\theta} v$ curves. For K_R = 3.2 and R $\geq$ 9.0, there is no intercept. This is consistent with Equation (VIII-5) which shows maximum rate gain to be 3.18 for R = 9.0 deg/sec.

The plot also shows (for example) that if K_R = 3.0 and R = 9.0, the steady state lag angle is 35° - consistent with Equation (VIII-4) - and $\dot{\theta} g = \dot{\theta} v$ = 11.0 deg/sec.

Finally, the plot indicates that as R becomes larger, the maximum allowable K_R becomes smaller. Note that this restriction on K_R is independent of acceleration level.

E. OPTIMUM RATE GAIN

Using trajectory relations and Equation (VIII-1), it can be shown that the necessary condition for deadbeat response from a steady-state ramp maneuver condition is:

$$\theta e \cos^2 \theta c = \frac{R^2}{2\,\alpha} \qquad \text{(VIII-6)}$$

where α is vehicle acceleration in deg/sec^2

Since the left side of this equation has a finite maximum value, we are led to restriction on vehicle acceleration. That is:

Minimum Acceleration for Deadbeat Response

$$(\alpha)\ \text{min} = \frac{R^2}{47.2} \qquad \text{(VIII-7)}$$

(this is independent of rate gain)

Ex: for $R = 9.0$ (α) min = 1.71 deg/sec^2
for $R = 9.5$ (α) min = 1.91 deg/sec^2

Optimum Rate Gain

Using Equations (VIII-6) and (VIII-4), Figure VIII-2 has been plotted to show optimum K_R versus acceleration.

F. CONCLUSIONS AND RECOMMENDATIONS

(1) Observed performance of FACS during air bearing test is consistent with analysis herein. During this test, FACS (yaw) parameters were

K_R = 3.2 sec

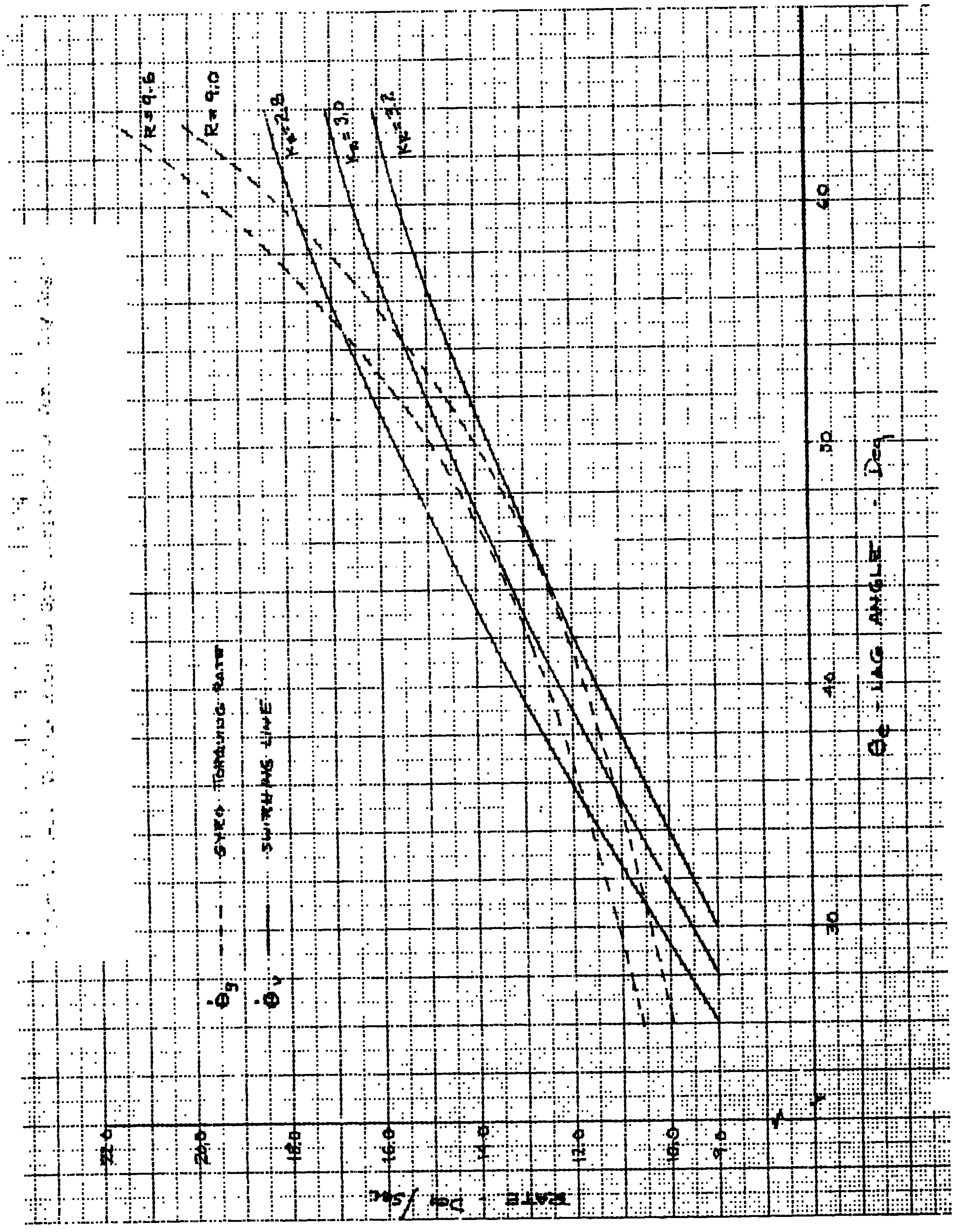
R = 9.5 deg/sec

Figure VIII-1 shows that no steady-state condition can exist under these circumstances.

(2) To constrain the ramp maneuver lag angle, reset FACS rate gain in accordance with Figure VIII-2.

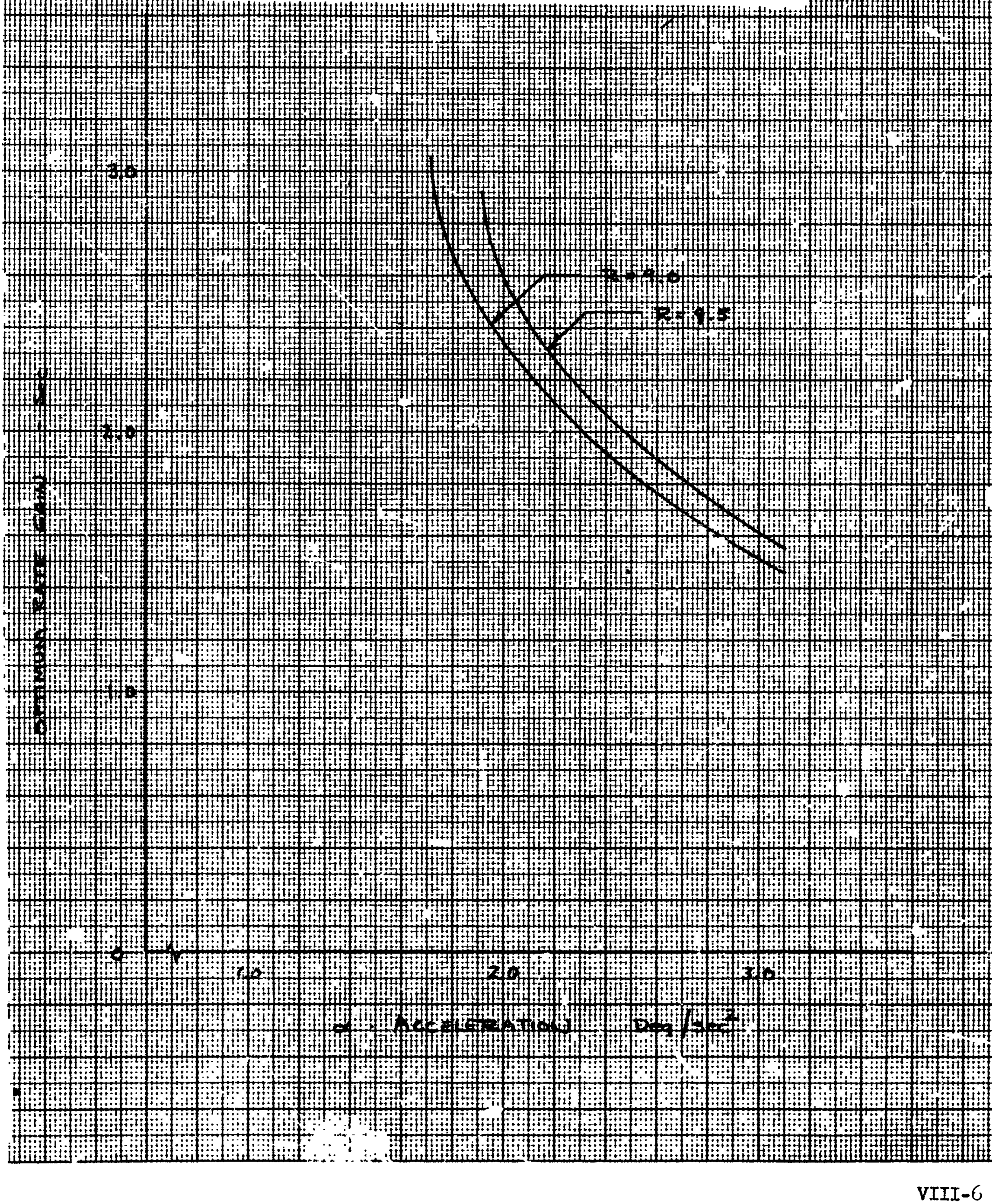
Pitch and Yaw $K_R = 2.8$

(3) Computer correlation will require mechanization of Equation (VIII-1).



K = 9.6
K = 9.0
Kp = 2.8
Kp = 3.0
Kp = 3.2
Θg - - - GYRO TURNING RATE
Θv —— SWIVLING LINE
22.0
20.0
18.0
16.0
14.0
12.0
10.0
9.6
30
40
50
60
RATE Deg/sec
Θe - LAG ANGLE - Deg

Figure VIII-2. Optimum Rate Gain Versus Acceleration



Appendix IX

EXPLANATION OF THE DEFERMENT OF ROLL SLAVING UNTIL COMPLETION OF ATTITUDE CAPTURE

Let $\vec{i}$, $\vec{j}$, $\vec{k}$ represent body-fixed orthogonal unit vectors aligned with the vehicle roll, pitch and yaw axis, respectively. In the ideal case, when the vehicle is captured to the gyros, all of the gyro gimbal angles are zero and the vehicle body axes, $\vec{i}$, $\vec{j}$, $\vec{k}$, are aligned with the desired inertially-fixed reference axes which will be represented by the orthogonal unit vectors, $\vec{I}$, $\vec{J}$, $\vec{K}$. The arrangement of the gyro gimbals is then as depicted in Figure IX-1.

For any arbitary orientation of the vehicle the inertially-fixed axes are related to the body-fixed axes by an orthogonal transformation. Thus:

$$\begin{pmatrix} \vec{I} \\ \vec{J} \\ \vec{K} \end{pmatrix} = (T) \begin{pmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{pmatrix} \qquad \text{(IX-1)}$$

where:

$$(T) = \begin{pmatrix} t_{11}, & t_{12}, & t_{13} \\ t_{21}, & t_{22}, & t_{23} \\ t_{31}, & t_{32}, & t_{33} \end{pmatrix}$$

is an orthogonal matrix. The roll and pitch gimbal angles, ϕ_P and θ, of the pitch gyro, and the roll and yaw gimbal angles, ϕ_Y and ψ, of the yaw gyro are then, in general, different from zero.

For present purposes it will be assumed that the gyros are perfect so that the spin vectors of the gyros remain inertially-fixed; i.e., there is no drift. In this case any maneuver which results in the alignment of the body-fixed axes, $\vec{i}$, $\vec{j}$, $\vec{k}$, with the inertially-fixed axes, $\vec{I}$, $\vec{J}$, $\vec{K}$, will bring all the gyro gimbal angles to zero and, conversely, any maneuver that results in bringing the gyro gimbal angles to zero will align the body-fixed axes with the inertially-fixed axes.

Since the spin vectors of the gyros are orthogonal it is apparent that a maneuver which brings the roll gimbal and the pitch gimbal of the pitch gyro to zero will automatically result in bringing the roll gimbal of the yaw gyro to zero. Such a maneuver can be made by performing the following sequence of rotations, which will bring all gimbal angles to zero.

a_1. Rotate about the $\vec{i}$ axis through an angle, ϕ_P, to bring the roll gimbal of the pitch gyro to zero.

b_1. Rotate about the $\vec{j}$ axis through an angle, θ, to bring the pitch gimbal of the pitch gyro to zero.

c_1. Rotate about the $\vec{k}$ axis through an angle, ψ_*, to bring the yaw gimbal of the yaw gyro to zero.

The transformation of axes associated with this sequence of rotations must correspond to the transformation (T), since the maneuver results in the alignment of the body-fixed axes with the inertially-fixed axis. Hence:

$$(T) = \begin{pmatrix} \cos\psi*, & \sin\psi*, & 0 \\ -\sin\psi*, & \cos\psi*, & 0 \\ 0, & 0, & 1 \end{pmatrix} \begin{pmatrix} \cos\theta, & 0, & -\sin\theta \\ 0, & 1, & 0 \\ \sin\theta, & 0, & \cos\theta \end{pmatrix} \begin{pmatrix} 1, & 0, & 0 \\ 0, & \cos\phi_P, & \sin\phi_P \\ 0, & -\sin\phi_P, & \cos\phi_P \end{pmatrix} \quad \text{(IX-2)}$$

$$= \begin{pmatrix} \cos\psi*\cos\theta, & \cos\psi*\sin\theta\sin\phi_P + \sin\psi*\cos\phi_P, & -\cos\psi*\sin\theta\cos\phi_P + \sin\psi*\sin\phi_P \\ -\sin\psi*\cos\theta, & -\sin\psi*\sin\theta\sin\phi_P + \cos\psi*\cos\phi_P, & \sin\psi*\sin\theta\cos\phi_P + \cos\psi*\sin\phi_P \\ \sin\theta, & -\cos\theta\sin\phi_P, & \cos\theta\cos\phi_P \end{pmatrix}$$

Alternatively, the gyro gimbal angles may be brought to zero by performing the following sequence of rotations:

a_2. Rotate about the $\vec{i}$ axis through an angle, ϕ_Y, to bring the roll gimbal of the yaw gyro to zero.

b_2. Rotate about the $\vec{j}$ axis through an angle, ψ, to bring the yaw gimbal of the yaw gyro to zero.

c_2. Rotate about the $\vec{k}$ axis through an angle, $\theta*$, to bring the pitch gimbal of the pitch gyro to zero.

Because of the orthogonality of the spin vectors of the gyro this maneuver will also result in bringing the roll gimbal of the pitch gyro to zero and will result in the alignment of the body-fixed axes with the inertially-fixed axes. Consequently, the transformation (T) must also be given by:

$$(T) = \begin{pmatrix} \cos\theta*, & 0, & -\sin\theta* \\ 0 & , 1, & 0 \\ \sin\theta*, & 0, & \cos\theta* \end{pmatrix} \begin{pmatrix} \cos\psi, & \sin\psi, & 0 \\ -\sin\psi, & \cos\psi, & 0 \\ 0 & , 0 & , 1 \end{pmatrix} \begin{pmatrix} 1, & 0 & , 0 \\ 0, & \cos\phi_Y, & \sin\phi_Y \\ 0, & -\sin\phi_Y, & \cos\phi_Y \end{pmatrix} \quad \text{(IX-3)}$$

$$= \begin{pmatrix} \cos\theta*\ \cos\psi, & \cos\theta*\sin\psi\cos\phi_Y + \sin\theta\sin\phi_Y, & \cos\theta*\sin\psi\sin\phi_Y - \sin\theta*\cos\phi_Y \\ -\sin\psi & , \cos\psi\ \cos\phi_Y & , \cos\psi\sin\phi_Y \\ \sin\theta*\cos\psi, & \sin\theta*\sin\psi\cos\phi_Y - \cos\theta*\sin\phi_Y, & \sin\theta*\sin\psi\sin\phi_Y + \cos\theta*\cos\phi_Y \end{pmatrix}$$

Upon equating appropriate elements of (T) given by Equations (IX-2) and (IX-3) the following relationships are obtained:

$$\sin\psi* = \frac{\sin\psi}{\cos\theta} \quad \text{(IX-4)}$$

$$\sin\theta* = \frac{\sin\theta}{\cos\psi} \quad \text{(IX-5)}$$

$$\cos\psi*\cos\theta = \cos\theta*\cos\psi \quad \text{(IX-6)}$$

$$\cos\theta\sin\phi_P = -\sin\theta*\sin\psi\cos\phi_Y + \cos\theta*\sin\phi_Y \quad \text{(IX-7)}$$

$$\cos\theta\cos\phi_P = \sin\theta*\sin\psi\sin\phi_Y + \cos\theta*\cos\phi_Y \quad \text{(IX-8)}$$

Upon substituting from Equations (IX-4) to (IX-6), Equations (IX-7) and (IX-8) can be expressed as follows:

$$\sin\phi_P = -\tan\theta\tan\psi\cos\phi_Y + \frac{\cos\theta*}{\cos\theta}\sin\phi_Y \quad \text{(IX-9)}$$

$$\cos\phi_P = \tan\theta\tan\psi\sin\phi_Y + \frac{\cos\theta*}{\cos\theta}\cos\phi_Y \quad \text{(IX-10)}$$

Equations (IX-9) and (IX-10) lead to:

$$\sin (\phi_Y - \phi_P) = \tan \theta \tan \psi \qquad \text{(IX-11)}$$

$$\cos (\phi_Y - \phi_P) = \frac{\cos \theta^*}{\cos \theta} = \frac{\cos \psi^*}{\cos \psi} \qquad \text{(IX-12)}$$

The foregoing results show that in general ψ^* is not equal to ψ and θ^* is not equal to θ and ϕ_Y is not equal to ϕ_P. In particular, ϕ_Y and ϕ_P are equal only when either θ or ψ is zero. This may be stated as follows: when attitude of the vehicle is such that neither inner gimbal angle is zero then if the spin vectors of the gyros are orthonogal the roll gimbal angles of the gyros are not equal; specifically, if $\phi_P = 0$, $\phi_Y \neq 0$.

If the capture procedure were as follows:

(1) Despin and capture in roll to the roll gimbal of the pitch gyro,

(2) Slave the roll gimbal of the yaw gyro,

(3) Capture in pitch and yaw

then, in step (2), to the extent that neither θ nor ψ might be zero at this time, the torque applied to slave the roll gimbal of the yaw gyro would force the spin vectors of the gyros to become non-orthogonal. This would be equivalent to causing the yaw gyro to drift. The error so introduced can be substantial. For example, if $\theta = \psi = 10$ deg and $\phi_P = 0$, ϕ_Y would be about 1.8 deg. The error introduced by slaving ϕ_Y to zero under these conditions, instead of allowing the proper value of 1.8 deg to remain, would be reflected later in a yaw error at capture.

In the planned capture procedure this error is avoided by reversing steps (2) and (3); i.e., the vehicle is captured in pitch (and yaw) before the yaw gyro is slaved in roll. In this way, at the time slaving is begun, ϕ_Y is nominally zero. In practice, ϕ_Y may differ slightly from zero at the initiation of slaving because of residual drifts which may occur in either the pitch or the yaw gyros. (Predictable drift errors would have been corrected in the initial offset of the gyro gimbals.) Slaving of the yaw gyro in roll prior to pitch/yaw capture has no advantage with respect to this residual drift.

As a general principle, the gyros should be torqued only when the inertial position of the axis about which the torque is applied is known. Otherwise the effect of the torquing on the inertial reference held by the gyro cannot be predicted. Slaving of the yaw gyro in roll prior to pitch/yaw capture violates this principle.

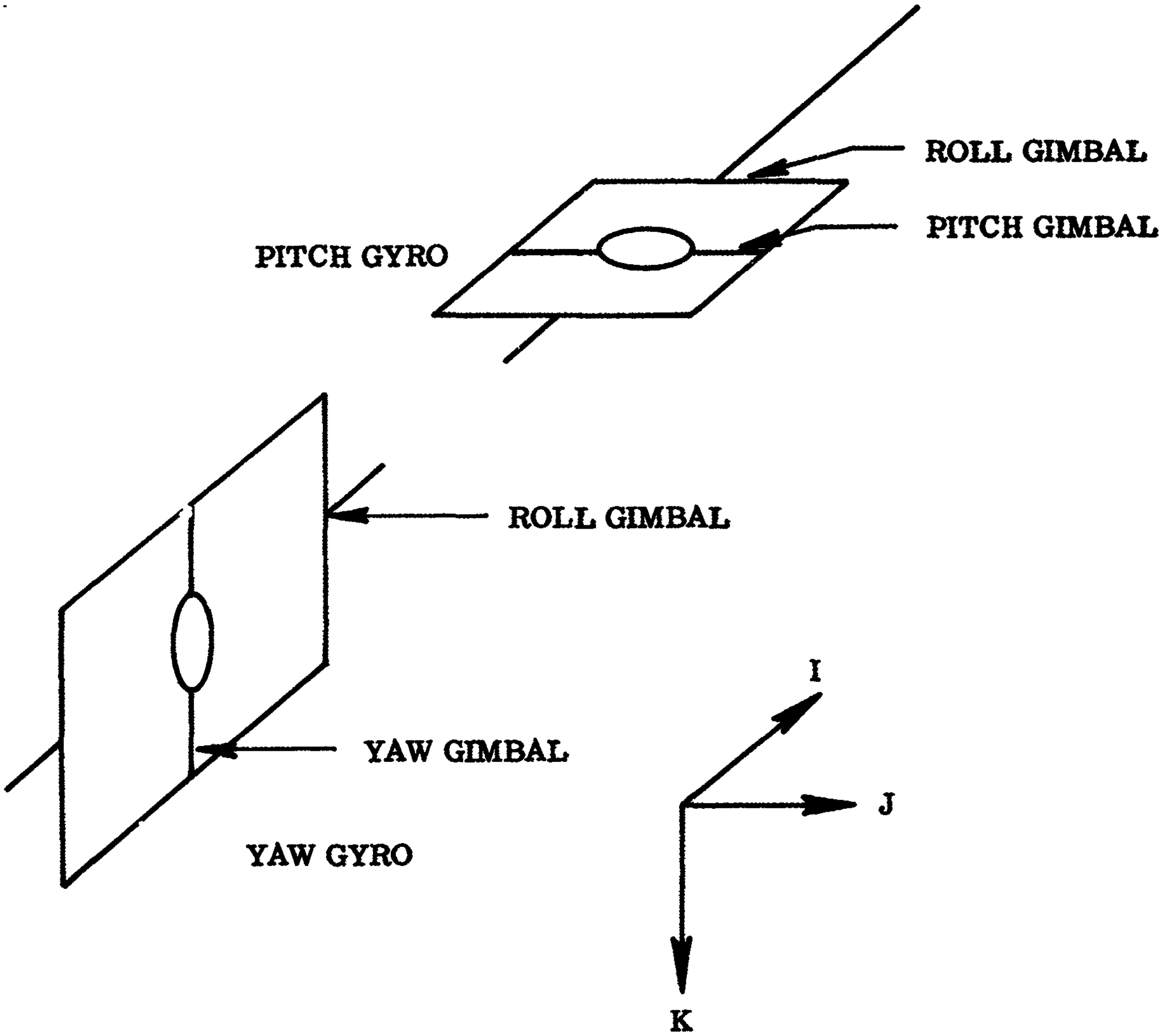


Figure IX-1. Arrangement of Gyro Gimbals

Appendix X

CORRECTION OF THE EFFECT OF INNER GIMBAL ANGLE ON TORQUING RATE

Attention has recently been directed to the gyro torquing error that is made in executing "ramp" type maneuvers with the Aerobee ACS due to the neglect of the effect of inner gimbal angles on torquing rate. This memo is written to describe the proposed method of correcting for this effect in the "product improved" version of the system.

The gyro torquing rate is given by

$$\dot{\theta}_c = \frac{T}{H} \frac{1}{\cos(\theta_c - \theta_v)} \tag{1}$$

where θ_c is the gyro angle (in pitch or yaw) relative to an inertially fixed reference, θ_v is the vehicle angle relative to the inertial reference, T is the torque applied to the gyro and H is the gyro angular momentum. The nominal torquing rate of 9 deg/sec is obtained when $\theta_v = \theta_c$, $T = T_o$, and $H = H_o$ where T_o and H_o are the nominal values of T and H. For the P-I system the planned technique for compensating for off-nominal conditions is to obtain a D.C. measure of $\dot{\theta}_c$, integrate this measure and then to stop gyro torquing when the integration indicates that the desired value of θ_c has been reached. Circuits for implementing this scheme have been worked out. However, they are applicable only for the case where θ_v remains equal to θ_c.

Because of the lag angle which arises in executing ramp maneuvers, the difference between θ_v and θ_c becomes significant. This lag angle is not constant in time during a maneuver and also varies with the gas pressure and the magnitude of the maneuver. Hence a "programmed" compensation scheme does not appear to be feasible. The compensation scheme should be based upon the measurement of the lag angle and must be applicable to the maximum lag angle range that may be encountered. This range is from zero to about 30 degrees.

Compensation for lag angles in this range can be made to sufficient accuracy by adding a correction term instead of performing the multiplication by $1/\cos(\theta_c - \theta_v)$ indicated by Eq. (1). This may be demonstrated as follows: The torque-momentum ratio can be written

$$\frac{T}{H} = \frac{T_o}{H_o} (1 + \epsilon_1) \tag{2}$$

where ϵ_1 is the relative departure of $\frac{T}{H}$ from its nominal value. Past analyses have indicated that the maximum value of ϵ_1 will be about 0.05. Defining ϵ_2 by

$$\epsilon_2 = \frac{1}{\cos(\theta_c - \theta_v)} - 1 \tag{3}$$

it is found that when $|\theta_c - \theta_v| \leq 30$ deg. the maximum value of this quantity is about .15. Now using Eqs. (2) and (3), Eq. (1) can be written

$$\dot{\theta}_c = \frac{T_o}{H_o} (1 + \epsilon_1)(1 + \epsilon_2) \tag{4}$$

$$= \frac{T_o}{H_o} (1 + \epsilon_1) + \frac{T_o}{H_o} \epsilon_2 + \frac{T_o}{H_o} \epsilon_1 \epsilon_2$$

The maximum value of the last term is $9(.05)(.15) = .0675$ deg/sec. If this term is dropped the largest error that would be made in a 90 degree maneuver would be about .675 deg. This error would occur only in very extreme cases, i.e., when T/H is most off nominal, when the lag angle is greatest and when the maneuver is large, all conditions occurring simultaneously. The error that is made by using the approximation

$$\dot{\theta}_c = \frac{T_o}{H_o} (1 + \epsilon_1) + \frac{T_o}{H_o} \epsilon_2 \tag{5}$$

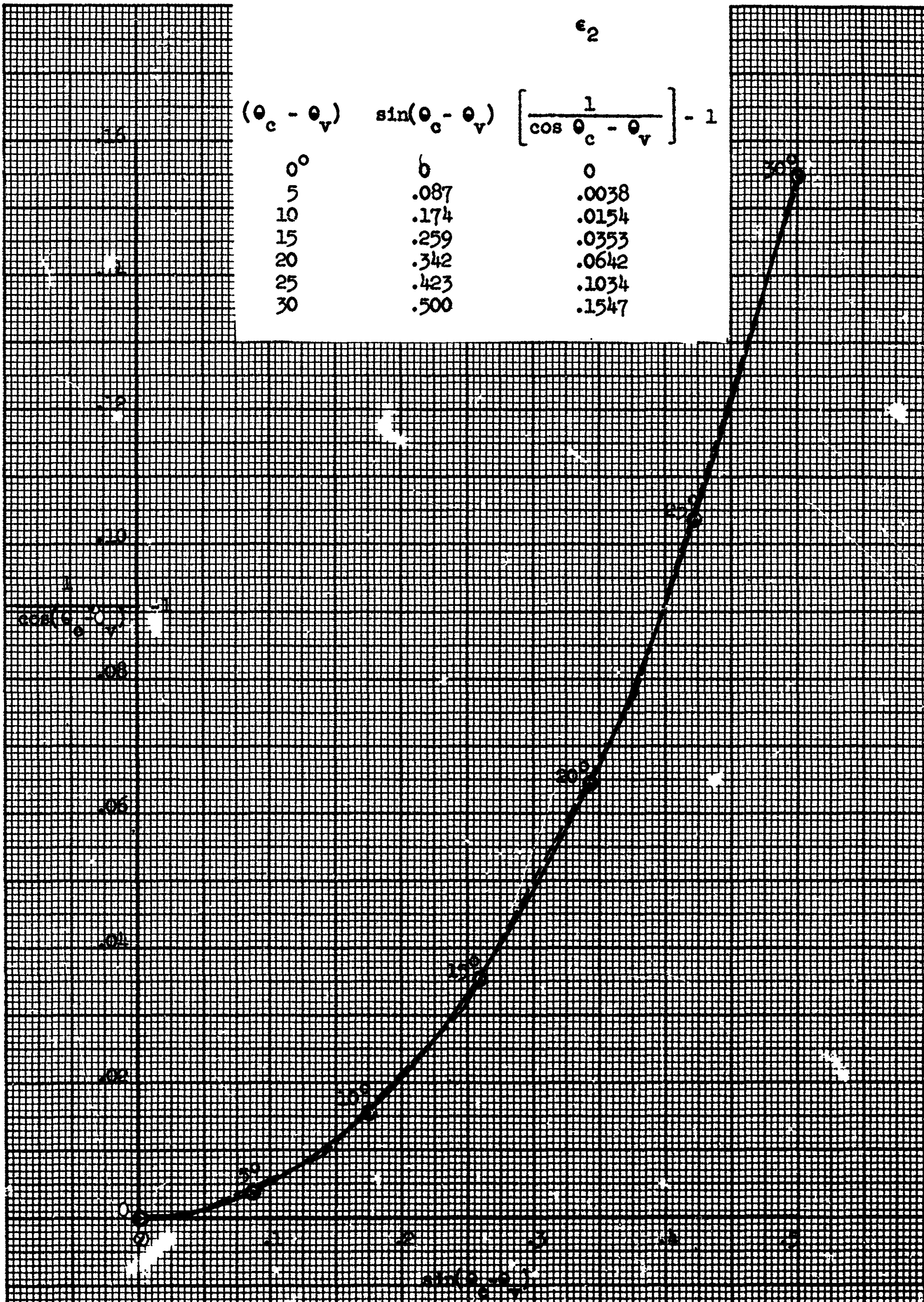
$$= \frac{T}{H} + \frac{T_o}{H_o} \epsilon_2$$

for the torquing control circuit thus appears to be tolerable. Since the first term on the right hand side is already implemented, it remains only to add the second term, specifically $\left|T_o/H_o\right| \epsilon_2$.

A signal proportional to $\left(T_o/H_o\right)\epsilon_2$ can be generated by processing the gyro signal which is proportional to $\sin(\theta_c - \theta_v)$. The relationship between ϵ_2 and $\sin(\theta_c - \theta_v)$ is shown in Figure 1. As shown by the dotted lines in the figure, ϵ_2 can be approximated by four broken line segments with a maximum error of about .001. This error is negligible since it corresponds to a maximum error .009 deg/sec in gyro torquing which would produce a maximum error of .09 degree for a 90 degree maneuver.

Since the function is monotonic it can be conveniently generated with the use of diodes. A schematic of a possible circuit for this purpose is shown in Figure 2. A one percent error in the conversion of the AC gyro synchro signal to DC would correspond to a maximum error in $\dot{\theta}_c$ in the order of .01 deg/sec which would be negligible.

Compensation for the effect of inner gimbal angle on gyro torquing is required only for pitch and yaw. By use of a suitable switching arrangement, a single torquing control circuit can be used to service both pitch and yaw. Since the roll angle is measured on the outer gyro gimbals the torque always remains orthogonal to the gyro momentum. In addition the single axis platform follows so closely that there is no significant lag angle. If inner roll gimbals had been used for the single axis platform no compensation for lag angle effects would have been required.



ϵ_2

$(\theta_c - \theta_v)$	$\sin(\theta_c - \theta_v)$	$\left[\frac{1}{\cos \theta_c - \theta_v}\right] - 1$
0°	0	0
5	.087	.0038
10	.174	.0154
15	.259	.0353
20	.342	.0642
25	.423	.1034
30	.500	.1547

Figure 1. Approximation for Lag Angle Compensation

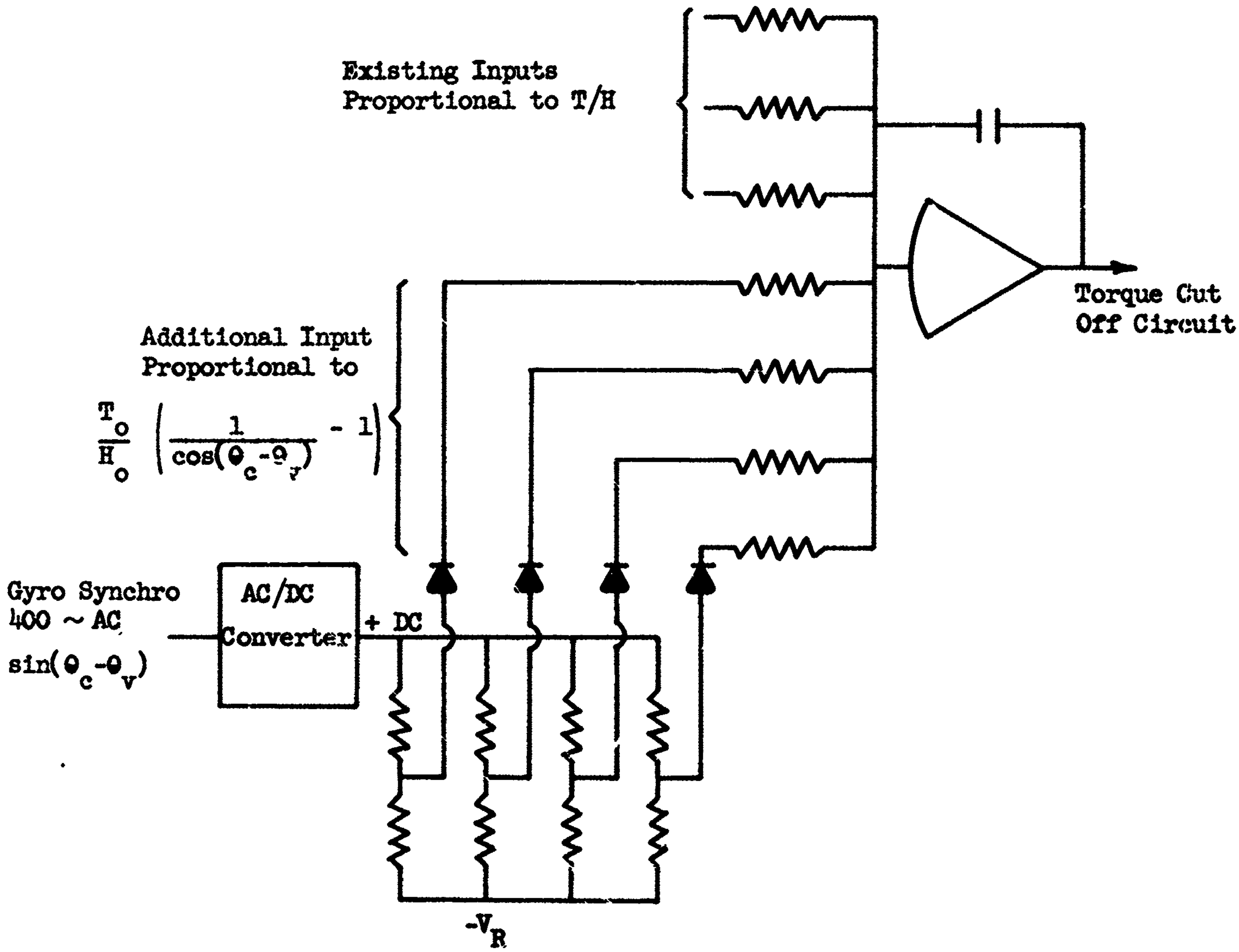


Figure 2. Schematic - Lag Angle Compensation Circuit